REPORT OF

THE NATIONAL PARK SERVICE
GREATER YELLOWSTONE INVENTORY AND MONITORING NETWORK:
VITAL SIGNS MONITORING WORKSHOP

MAY 6-8, 2003

Strand Union Building, Montana State University
Bozeman, Montana

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http://www.nature.nps.gov/im/units/gryn/index.shtml

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<u>EXECUTIVE SUMMARY</u>

This report summarizes the events of the *Vital Signs Monitoring Workshop* hosted by the Greater Yellowstone Inventory and Monitoring Network (GRYN) May 6-8, 2003 at the Strand Union Building on the campus of Montana State University, Bozeman, Montana. This workshop is part of the extensive process used to select vital signs to be included in the GRYN Vital Signs Monitoring Plan. The overall goal of the meeting was to apply priority setting to a list of proposed candidate vital signs to be monitored as a means for determining the long-term ecosystem health of the parks of the GRYN. Throughout the workshop, participants also undertook the task of peer review of the ecosystem conceptual models and the decision support system created by the GRYN workshop planning team. (Please see Appendix A for the complete workshop agenda.)

The first day of the workshop was designed to create a shared knowledge and understanding of the National Inventory and Monitoring (I&M) Program, the GRYN and the process by which the workshop planning team developed the list of proposed candidate vital signs used throughout the *Vital Signs Monitoring Workshop*. The goals of the National I&M Program were explained to the participants, as was the need to create a comprehensive and integrative program. Because of time and budgetary constraints, prioritization of vital signs is fundamental, and the primary objective of this workshop was to use experts' knowledge to undertake one step of the prioritization process. Participants were informed that choices they made during this workshop did not constitute a final list of vital signs to be monitored by the GRYN, but that their decisions would be used by the GRYN staff and Technical Planning Committee to make recommendations to the Board of Directors for final approval in August 2003.

During the second day of the workshop, participants were divided into resource-based breakout groups as follows: air quality and climate (joint group), geology and geothermal (joint group), aquatics and water quality (joint group), human use, invertebrates, terrestrial vegetation, terrestrial vertebrates. Using a list of proposed candidate vital signs and information such as the justification given through the conceptual model process or the Delphi survey process and proposed metrics, the breakout groups used a worksheet to evaluate each candidate vital sign using a predetermined set of desirable characteristics. The completion of these worksheets required current knowledge about the ecological relevance, response variability, management relevance, feasibility of implementation, interpretation and utility of the proposed vital sign. (Please see Appendix B for the complete set of selection criteria.) These data were given to the workshop data manager and entered into the decision support system Access database in real time to produce a ranked list of candidate vital signs. (Please see Appendix I for the ranked list of candidate vital signs.)

On the third day of the workshop, participants were given the opportunity to evaluate the ranked list of candidate vital signs and give overall comments. Comments are given in more detail in the body of this report. Participants then engaged in an exercise to determine the spatial and temporal scales within which data about each candidate vital sign could be collected or evaluated. The results of this exercise will be used to evaluate the utility of the vital signs throughout various spatial and temporal scales. This information will be used to summarize the spatial sampling design for the parks.

OVERVIEW OF THE GRYN

GRYN Background Information

The Mission of the National Park Service (NPS) is "to conserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment of this and future generations". To uphold this goal, the NPS created the Natural Resource Challenge in 2000 to encourage National Parks to focus on the preservation of the nation's natural heritage through science, natural resource inventories and expanded resource monitoring and management. This Challenge was legally guided by the *National Parks Omnibus Management Act of 1998*. Through the Natural Resource Challenge, the 265 parks of the NPS were placed into seven regions and, subsequently, organized into thirty-two Inventory and Monitoring Networks, based on geographic and ecological similarities. The overarching goal of the Networks can be summarized by the following quote from the NPS Advisory Board in July 2001: "A sophisticated knowledge of resources and their condition is essential. The Service must gain this knowledge through extensive collaboration with other agencies and academia, and its findings must be communicated to the public. For it is the broader public that will decide the fate of these resources". The goals of the Networks are:

- To inventory the natural resources and park ecosystems under NPS stewardship;
- To determine their nature and status;
- To monitor park ecosystems to better understand their dynamic nature and condition;
- To provide reference points for comparisons with other altered environments;
- To integrate natural resources inventory and monitoring information into NPS planning, management and decision-making.

The Greater Yellowstone Area (GYA) encompasses 18 million acres in three states—Montana, Wyoming and Idaho. Six National Forests and three National Wildlife Refuges lie within this area. Known as one of the largest intact natural areas in the contiguous United States, it has an enormous variety of vegetative communities that boast stable grizzly bear populations, trumpeter swan wintering grounds, free-ranging bison and the largest elk herd in North America. However, because of its wild nature, the GYA is attracting widespread development, in turn creating new disturbances to flora and fauna. The GRYN encompasses the GYA, which consists of four National Park Service protected areas: Bighorn Canyon National Recreation Area (BICA), Grand Teton National Park (GRTE), John D. Rockefeller Memorial Parkway (JODR) and Yellowstone National Park (YELL).

The GRYN was approved by a charter in 2001 and consists of a Board of Directors, Technical Planning Committee, Science Committee and GRYN staff. The Board of Directors (BOD) is comprised of the park superintendents (or his/her appointee) from each of the three GRYN parks and the Research Coordinator for the Rocky Mountains-Cooperative Ecosystems Studies Unit. The BOD directs the GRYN and provides oversight, as well as approving budgets, work plans and the final monitoring plan. The Technical Planning Committee (TPC) is responsible for strategic decisions, such as writing work plans, identifying subject experts as scientific advisors and providing the GRYN with current data and methodologies being used by the parks. A representative from each park sits on the TPC, as well as the Inventory and Monitoring (I&M) Program Manager and the Research Coordinator for the Rocky Mountains-Cooperative

Ecosystems Studies Unit. Members of the Science Committee (SC) are chosen from regional universities and other scientific agencies. The role of the SC is to provide scientific background, suggestions and review that will be used to choose vital signs and to assist in the creation of sampling designs and protocols. The GRYN staff consists of a Program Manager, Cartographic Technician, Communications Director and Writer/Editor, all of whom are based at the Forestry Sciences Lab at Montana State University in Bozeman, Montana and are hosted by the USGS-Northern Rocky Mountain Science Center. In addition, Bighorn Canyon National Recreation Area houses a GRYN ecologist and Grand Teton National Park hosts a GRYN hydrologist. The positions of Data Manager and Quantitative Ecologist, both to be based in Bozeman, will be filled in 2003.

The GRYN is focusing its efforts in three primary areas: data management, inventories and long-term monitoring. Because monitoring vital signs is one of the primary goals of the GRYN, the selection of these vital signs and how best to measure them is an integral part of the success of the program. In order to assure a secure scientific backing, the GRYN formed partnerships with universities, non-profits and park personnel. In 2001 the GRYN joined with the University of Idaho-College of Natural Resources to conduct an internet-based survey of park personnel, university faculty, environmental groups and other agencies. This "Delphi" survey process consisted of three rounds of questioning meant to identify and rank the most important ecosystem components, conditions and processes. Over 100 individuals responded to this survey.

In addition to the Delphi surveys, the GRYN took on the task of developing conceptual ecosystem models to understand the complex nature of the interactions between ecosystem components. These conceptual models are being used to better understand the ecosystems under study and provide solid scientific information based in literature as well as to help guide those who will choose the vital signs for monitoring. The models show drivers, stressors, ecological responses, outcomes and indicators that will warn managers of ecosystem changes.

Along with the Delphi survey and conceptual models, the GRYN has completed a literature review and park-specific workshops. The literature review allows the GRYN quick access to a variety of pertinent scientific studies that have been performed in the GYA and, specifically, in the GRYN parks. The GRYN also hosted park-specific workshops, preceding the *Vital Signs Monitoring Workshop*, where park managers were given the opportunity to peer review the conceptual models and selection criteria used by the GRYN during the *Vital Signs Monitoring Workshop*. (Workshop reports from the park-specific workshops are available upon request.)

Purpose of the *Vital Signs Monitoring Workshop*

The list of vital signs to be monitored by the GRYN will be approved by the Board of Directors in August 2003. In order to narrow down an extensive list of possible indicators to a manageable few that will become the final list, the GRYN, under guidance from the National I&M Program, hosted the *Vital Signs Monitoring Workshop*. The goal of this workshop was to assemble subject-area experts to give guidance on which proposed candidate vital signs they believed were most beneficial to the GRYN in keeping with the Service-wide Network goals set forth by the NPS. In order to complete these tasks, the workshop planning team created a list of thirteen selection criteria—a set of yes/no questions to be answered by workshop participants, with space provided for helpful comments corresponding to the criteria. (Please see Appendix H for the complete table of comments.) The selection criteria were developed to determine which of the candidate vital signs contained those desirable characteristics that were deemed important through a literature review and peer review during the park-specific workshops prior to the *Vital Signs Monitoring Workshop*. The selection criteria worksheets were completed by the participants and then entered into the decision support system Access database the afternoon and evening of the second day of the workshop. This allowed the workshop planning team to present the results to the participants during the third day of the workshop, allowing for comment by the participants on both the process and results.

Approximately 150 individuals were invited from a variety of government, non-government, academic and non-profit organizations, with fifty-six attending. Organizations represented include: Yellowstone National Park, Grand Teton National Park, Bighorn Canyon National Recreation Area, Rocky Mountains-Cooperative Ecosystems Studies Unit, National Park Service-Air Resources Division, U.S. Geological Survey-Water Resources Division, U.S. Geological Survey-Northern Rocky Mountain Science Center, Environmental Protection Agency, Greater Yellowstone Coordinating Committee, U.S. Forest Service, Wyoming Game and Fish, Snowcap Hydrology, Yellowstone Ecological Research Center, Montana Natural Heritage Program, Montana State University, Montana State University-Big Sky Institute, Idaho State University, Iowa State University, University of Oregon, University of Montana, University of Wyoming and the Wyoming Natural Diversity Database. For a complete list of participants and contact information, please see Appendix C.

Workshop Planning Team

The workshop planning team consisted of a group of individuals who helped create the concept behind the *Vital Signs Monitoring Workshop*, establish workshop goals, generate useful selection criteria and produce a decision support system database. Cathie Jean, Program Manager for the GRYN, was the leader of workshop planning and implementation. Tom Olliff, Chief of Resources at Yellowstone National Park and a member of the TPC, was an integral part of the vital signs selection process and provided helpful critique. Glenn Plumb, Supervisory Wildlife Biologist at Yellowstone National Park, was the author of the selection criteria, ranking process and development of narrative and schematic conceptual models. Ann Rodman, Supervisory GIS Specialist at Yellowstone National Park and a member of the TPC, created the version of the decision support system Access database used during the workshop and provided oversight during data entry and analysis. Duncan Patten, Research Professor at Montana State University, was instrumental in the conceptual model design, as well as author of many individual models and narratives. Bob Hall, Assistant Professor at the University of Wyoming, was the aquatics conceptual model author. Dan Tinker, Assistant Professor at the University of Wyoming, authored many of the terrestrial vegetation conceptual models. Anne Schrag, Communications Director for the GRYN, provided logistical support during the workshop and prepared this workshop report.

The Future: Where do we go from here?

After completion of the *Vital Signs Monitoring Workshop*, the GRYN will work closely with the TPC to choose and recommend vital signs for BOD approval. The GRYN will begin this process by hosting the Technical Planning Committee Vital Signs Selection Meeting at Mammoth Hot Springs, Yellowstone National Park, in June 2003. During this meeting, the GRYN staff and Technical Planning Committee members will choose candidate vital signs to submit to the Board of Directors for approval. In order to select the appropriate vital signs for monitoring, they will have at their disposal a conceptual framework for the proposed vital signs, the ranked list of vital signs from the *Vital Signs Monitoring Workshop* and technical notes on highly ranked vital signs from all resource areas. After the vital signs selection has occurred, the Board of Directors will have final approval during an August 2003 meeting at Lake, Yellowstone National Park. Following this meeting, the GRYN will submit its Phase II Report in September 2003, outlining the process it took to choose the selected vital signs, including literature review, the Delphi survey, conceptual models and the workshop series. During the following year, 2004, the GRYN will undertake extensive research efforts to develop monitoring objectives and protocols that will be included in the Phase III Report, to be submitted in December 2004, along with the Draft Vital Signs Monitoring Plan for peer review. The final Vital Signs Monitoring Plan will be submitted in December 2005.

<u>VITAL SIGNS MONITORING WORKSHOP-DAY 1</u>

Objectives

The objectives of the first day of the *Vital Signs Monitoring Workshop* were as follows:

- To create a shared understanding of the NPS I&M Program and the Greater Yellowstone Network
- To inform participants of the process used to identify candidate vital signs
- To create an informal, open-forum discussion of the posted conceptual models as part of an evening social hour

Presentations

In order to accomplish these objectives, several presenters were asked to share information about the part of the workshop planning process with which they were involved. To open the meeting, Tom Olliff, Chief of Resources at Yellowstone National Park, shared the sentiment that this is a historic time in the life of the NPS with respect to a shift in focus from scenery management to natural resources management.

Introduction to the National Park Service Inventory & Monitoring Program
Steve Fancy, National I&M Program Coordinator

This introduction was followed by a presentation by Steve Fancy, National I&M Coordinator, about the national program perspective. He referred to the Natural Resource Challenge, which provides the funding for the I&M Program, as a "wave of change", giving true meaning to the phrase "science for parks, parks for science". The Challenge doubles the natural resource staff in the NPS. According to Fancy, goals of long-term monitoring include providing an early warning of change in order to eliminate non-action due to a lack of knowledge and resources. In addition, the I&M Networks are tasked with identifying what kinds of changes are acceptable, meanwhile focusing on the most significant ecological indicators because of time and money constraints. Fancy also focused on the need for partnerships between Networks and universities and other agencies, all the while keeping the information obtained through inventories and monitoring useful for many different divisions within the parks. The creation of Networks will allow for professional staff to design, implement and communicate the results of the I&M program throughout the Network parks.

GRYN Vital Signs Monitoring Plan
Cathie Jean, GRYN Program Manager

Cathie Jean, Program Manager for the GRYN, gave an overview of the GRYN, including the GRYN parks, operating procedures and budget estimates. Jean gave an overview of the process leading to the list of proposed candidate vital signs. The Delphi Internet survey consisted of three rounds of questions, with the third round including a ranking of indicator importance. One value of such a survey was the independent thinking that took place because participants were dispersed through time and space. However, this process also lacks statistical power. Ecosystem conceptual models were then created to show the most important components and linkages in key ecosystems throughout the parks of the GRYN and are backed by scientific literature. Jean then emphasized the importance of the process the participants would undergo during day two, and encouraged recording any comments that classify or justify answers given on the selection criteria worksheets.

Variability in Natural Systems and Monitoring Considerations

Duncan Patten, Research Professor, Montana State University

The focus of Duncan Patten's presentation was the application of historic range of variability to ecosystem management and monitoring. This presentation was requested, in part, to give participants a frame of reference for some of the selection criteria that dealt with the natural range of variability of certain proposed candidate vital signs. According to Patten, the historic range of variability helps in understanding the dynamic nature of ecosystems. In order to consider past conditions, one must include both natural and human-induced impacts, such as climate change, invasive species, etc. One method of evaluating the historic range of variability is through repeat photography, which gives a good representation of historic changes, as well as showing temporal and spatial variability, but also requires interpretation. Patten left participants with the question of whether the historic range of variability is a useful tool for monitoring at a variety of scales, as well as the question of "what do we do?" when the desired future condition does not match the historic range of variability or the present condition does match the historic range of variability.

The Role of Conceptual Models in Choosing Vital Signs

Glenn Plumb, Supervisory Wildlife Biologist, Yellowstone National Park
Duncan Patten, Research Professor, Montana State University
Dan Tinker, Assistant Professor, University of Wyoming
Bob Hall, Assistant Professor, University of Wyoming

Glenn Plumb, Supervisory Wildlife Biologist at Yellowstone National Park, was on detail with the GRYN during the winter of 2002-2003 with the specific task of helping to create a defensible vital signs selection process. Plumb went about this task by using graphic conceptual models as "problem solving vehicles" that illustrate the linkages among key environmental drivers, stressors, ecological effects, outcomes and measurable parameters that serve as ecological response signals. According to Plumb, the GRYN conceptual model formula was based off of work done in the Everglades, wherein eight steps were taken to create useful conceptual models that lead the GRYN to a list of vital signs to monitor. These steps include: 1) considering the spatial, temporal and ecological scales and boundaries; 2) identifying important elements of ecosystem structure and function; 3) identifying sources of anthropogenic or natural stressors of concern; 4) describing stressor mechanisms and routes of exposure or linkage; 5) identifying ecological receptors and at-risk components; 6) identifying ecological endpoints; 7) developing stress-effects causal pathways; and 8) identifying a particular structural framework for the graphics. Plumb stressed that the conceptual models designed for the GRYN were not meant to be complete ecosystems, rather to identify components of the systems that are often not considered, but are more informative than many other parts of the system that are easily recognized and used.

Following this presentation, Duncan Patten, Dan Tinker and Bob Hall, three of the five conceptual model authors for the GRYN, gave brief presentations on chosen models, in order to guide participants through this part of the process used to identify proposed candidate vital signs. A complete set of draft conceptual models presented at the workshop can be found in Appendix D.

Evening Conceptual Model Social Hour

On the evening of day one of the workshop, participants were invited to a social in which the draft conceptual models were displayed for peer review. Conceptual model authors contributed fifteen total models focusing on the following systems: lake, river, dry woodland, lodgepole pine, ponderosa pine, whitebark pine, mixed conifer, aspen, alpine and timberline (joint), riparian, wetland, shrubland, grassland, geothermal and Yellowstone National Park. These models were reproduced in 36"x 42" poster size at the social and participants were encouraged to discuss questions, concerns and comments with the authors and to "mark up" the posters with changes they believed would make the posters more informative or inclusive of important ecosystem processes. Dan Tinker, terrestrial systems model author, received many excellent and helpful comments during this time and thought that the social atmosphere was helpful. According to Bob Hall, aquatics conceptual model author, the peer review received during this social hour was very helpful, especially since the social occurred almost directly after the presentation of the models. Therefore, many participants came with questions or ideas already formulated and ready for discussion.

VITAL SIGNS MONITORING WORKSHOP-DAY 2

Objectives

The objectives for the second day of the *Vital Signs Monitoring Workshop* were as follows:

- To apply the selection criteria from the decision support system to each candidate vital sign in the topic area and provide results to the decision support system manager by 5:00 pm
- To document comments related to the scoring decisions that will be incorporated into a report for the Technical Committee and Science Committee

Breakout Group Sessions

Participants were directed to breakout rooms (one group per room, except for very small groups) and given the task of completing the selection criteria worksheet(s) for each vital sign assigned to that group. The number of assigned candidate vital signs ranged widely, from fifty-four in the terrestrial vegetation group to seven in the invertebrate group. However, the number of experts in each group also varied, from thirteen in the terrestrial vegetation group to three in both the invertebrate and human-use groups. In fact, the terrestrial vegetation group proved to be too large and, thus, was split into two groups after the lunch break in order to facilitate the scoring process. Although the terrestrial vertebrate group was also quite large, the group members had fewer candidate vital signs to score than the vegetation group. In addition, the vertebrate group found it helpful to designate threshold values from the beginning of the process in order to answer the criteria as efficiently as possible. The complete list of breakout group members can be found in Appendix E.

Each group was assigned a group moderator—usually the author of the conceptual model(s) that best applied to that breakout group. In addition, two professional facilitators were on hand throughout the three-day conference to answer questions about the consensus process and to guide groups whose assignments proved difficult. The groups were to use the following process to complete the selection criteria worksheets (please see Appendix F for a complete list of proposed candidate vital signs and Appendix B as a reference for the selection criteria worksheets):

- Decide on the appropriate name for the proposed candidate vital sign. The group could choose to:
  - keep the current candidate vital sign name
  - change the candidate vital sign name to be more informative
  - lump the candidate vital sign with another vital sign
  - split the candidate vital sign into multiple (two or more) new vital signs
- Choose the parks in which the candidate vital sign occurs or applies
- Answer each selection criteria by filling in the "yes" or "no" bubble on the worksheet
- Add comments that refer to one of the following:
  - the specific selection criteria statements
  - the broad topic group of selection criteria (i.e. "management relevance")
  - the vital sign as a whole

To aid the groups in using the selection criteria, the workshop planning team composed a short, descriptive phrase to better explain each of the statements. These explanations, along with the vital signs information, the schematic conceptual models, the narrative conceptual models and some appendices offering information specific to the selection criteria were included in breakout group notebooks. One notebook was given to each group. The vital signs information contained in this notebook was extremely lengthy and, therefore, is not included in full in this report. An example follows and the entire report is available upon request:

Channel dimensions Unique ID: AqHa_123

Primary Resource: Aquatic Habitats Secondary: Rivers and Streams

Why is this an important Vital Sign?

Riparian vegetation not only responds to changing channel geomorphology but plays a role in its formation. Any change in channel geomorphology will consequently alter the amount and distribution of the riparian community. Thus, channel geomorphological metrics may be a useful indicator of the condition of riverine and riparian systems. Altered hydrological conditions and concomitant degraded riparian systems play a role in channel changes. For example, changing regional hydrology or influences of upstream flow regulators, e.g., dams, will cause channels to adjust to new conditions and offer less or more habitat for riparian plant communities. The ratio of channel width to depth and channel sinuosity in relation to floodplain type can be combined to develop a channel index that would indicate whether the channel is being altered from expected geomorphic conditions. Decreasing width/depth ratios tend to indicate a degraded, incised channel; however, a greatly increasing width/depth ratio may result from excessive bank destabilization by ungulate use.

Metrics:

Variability and changes in channel cross section geometry and river length to floodplain length relationships.

The expanded explanations of the selection criteria and the appendices can be found in Appendix G of this report.

In order to decide on an appropriate name for the proposed candidate vital sign, the group generally went through much discussion. Many of the original candidate vital sign names did not seem as informative as possible to group members. This process occurred simultaneously with the lumping and splitting of vital signs. Obviously, the freedom to create new vital signs from those given was important for participants. This liberty also allowed the participants to feel more comfortable with the candidate vital sign name than if they had been limited to using those provided through the Delphi survey and conceptual models. However, one overall problem with the candidate vital sign names occurred when participants noted that some candidate vital signs were very specific (i.e. specific taxa), while others were broad (i.e. group of taxa, such as small-bodied mammals). Many times a potential vital sign would be a better indicator if its name were more descriptive (i.e. specific butterfly species instead of overall insect biodiversity). As was seen in earlier park-specific workshops, vital signs about which people know little or are perplexed tend to rank in the middle, whereas those vital signs about which people know a lot (possibly because they are more specific) tend to rank either very high or very low, depending on the circumstance.

The next step in the worksheet process was to choose in which parks the candidate vital sign occurs or applies. Many times the candidate vital sign applied to all three parks. However, occasionally the candidate vital sign would not apply in one or two parks. This occurred more often with Bighorn Canyon in the area of geothermal features and terrestrial vegetation. However, often Bighorn Canyon had candidate vital signs in which it was the only park that a species or community occurs or specific measurement applies. This outcome was expected by the workshop planning team.

The workshop planning team put much thought into the structure of the selection criteria and the possible ways of quantifying a response that is, in actuality, qualitative by nature. Originally designed as a coarse and fine filter criteria wherein participants would choose how many statements they agreed with (thus giving a specific "score" such as low, medium or high that corresponded with a number), the selection criteria evolved to become a set of thirteen "yes/no" questions based upon extensive literature review and National I&M Program guidance as to what makes a "good" ecological indicator. These thirteen questions were placed into five broader categories, including ecological relevance, response variability, management relevance, feasibility of implementation and interpretation and utility. By making the answers to these questions binary in nature, the workshop planning team believed that they would provide a way in which participants could complete the task on time and eliminate debates about semantics. As the "yes/no" answers were entered into the Access database, the database was programmed to convert and calculate the scores as follows:

- For those broad topic areas that contained only two questions (i.e. ecological relevance):
  - two "yes" answers=1.0 score
  - one "yes" answer and one "no" answer=0.5 score
  - two "no" answers=0 score
- For those broad topic areas that contained three questions (i.e. response variability):
  - three "yes" answers=1.0 score
  - two "yes" answers and one "no" answer=0.6 score
  - one "yes" answer and two "no" answers=0.3 score
  - three "no" answers=0 score

In addition to this scoring method, the workshop planning team decided on a weighting scheme for the broad topic areas. The scheme was decided upon after input from the park-specific workshops on which broad topic areas participants felt were most important in creating a useful indicator of ecosystem health. These weights were then multiplied by the broad topic area scores (explained above) to create the final score. The weights chosen were as follows:

- Ecological relevance=25%
- Response variability=25%
- Management relevance=20%
- Feasibility of implementation=15%
- Interpretation and utility=15%

Another aspect of the decision of which candidate vital signs to monitor includes the responsibility of National Parks to monitor those resources whose protection is required by law. Therefore, information on the legal relevance is included in the Access database in the form of which piece of legislation requires the protection of specific resources. After much debate throughout the park-specific workshops, the workshop planning team decided to omit this criteria as a decision to be made by the expert participants who attended the workshop.

Although the workshop planning team made every effort to insure that sufficient explanations of the selection criteria and background information were provided to the participants, the process of ranking the candidate vital signs still produced questions and concerns. Because many comments were shared between group members and not formally recorded, what follows is a rough summary of major topic areas of discussion.

Overall comments about the process and/or selection criteria

- Many individuals felt that there was a need to separate the drivers and stressors from the response variables in order to fairly evaluate them as candidate vital signs. Also, there was much discussion about incorporating both types of candidate vital signs to create a comprehensive monitoring plan.
- One conceptual model author noted that, while lumping and splitting certainly was helpful in some circumstances, occasionally, when a vital sign was split, it lost its relevance with respect to why it was originally nominated. For example, when "riparian associated animal species" is split into specific taxa vital signs, the importance of the community structure that made it a good indicator of riparian ecosystem health is lost.
- One participant felt that narratives accompanying the conceptual models would have proven helpful. Although the narratives contributed by the conceptual model authors were provided in the notebooks, along with the vital signs justification statements, the workshop planning team did not set aside specific time to review them or notify the participants of their existence. Sending these materials ahead of time would have allowed participants to review their contents and come with any prepared questions.
- Many participants felt it would have been helpful to do a "trial run" of a few vital signs in order to alert them of potential difficulties with the selection criteria. This did occur, to some extent, at the park-specific workshops, wherein participants were given the opportunity to progress step-wise through the selection criteria, alerting the workshop planning team of potential difficulties. These suggestions were then incorporated into the final selection criteria presented to the *Vital Signs Monitoring Workshop* participants.
- One participant observed that a particular candidate vital sign could be both affected by some driver or stressor and also be a driver or stressor for another vital sign.
- A moderator noted that the overall response to the list of proposed candidate vital signs was very positive.

Specific comments about the process and/or selection criteria

- The terrestrial vertebrates group mentioned that vertebrate and invertebrate monitoring should be stratified by habitat. In addition, this group added that the candidate vital sign "native species richness" caused more discussion and differences of opinion than any other candidate vital sign and, therefore, they feel it should be re-evaluated.

- One individual felt that the sagebrush community that constitutes an important part of Grand Teton National Park was overlooked.

Concerns with the interpretation of the selection criteria

- Many groups created a "threshold level" for agreement with a specific selection criterion. In some cases, this threshold level was inconsistent among candidate vital signs.
- Many of the groups felt that particular criteria were not specific enough in their original wording to be assigned a "yes" or "no" answer definitively. Therefore, groups had to go through a decision process in order to define what "yes" or "no" meant in these cases. Hopefully, in addition, the groups also recorded this reasoning in the comment section of the worksheet.
- Although the workshop planning team made a best effort to include park managers in each of the breakout groups, many groups still did not feel comfortable answering the management relevance criteria without further assistance. Many groups felt that someone with complete knowledge of the business plan standards, enabling legislation, GPRA goals, etc. should go through their answers and check them against these management standards.
- There was much disagreement about how long a "long-term dataset" had to be. Groups obviously defined "long-term" differently depending upon what types of data they were evaluating.
- Although participants were asked not to take into account whether or not another agency is currently monitoring a specific proposed candidate vital sign, one group chose to rank highly those candidate vital signs that are already being monitored. This group also had the task of evaluating many stressors to the environment; thus, changing the application of the selection criteria. The effects of this ranking method are not yet fully understood, but will certainly be taken into account by those making the final decisions about which vital signs should be monitored. This also brings up the fact that this ranking is not the sole determinant of which vital signs will be monitored by the GRYN. Many other factors will be evaluated.
- Some groups also mentioned that whether or not a candidate vital sign was "cost prohibitive" was not specific and, therefore, required the use of intuition in the ranking process.
- The air quality/climate group moderator noted that it is virtually impossible to distinguish between natural variation and human-induced variation, which was one of the selection criteria.
- The natural versus human-induced criterion also raised questions because of the circular relationship between human and natural drivers.

Concerns with the wording of the selection criteria

- The aquatics group moderator felt that the criterion concerning the candidate vital sign's helpfulness in identifying the causal mechanism of an ecological response was difficult to interpret. In addition, he noted that the criterion concerning low statistical power and variability was complicated because these two things were not thought to be the same and that it overlapped with the question concerning natural versus human-induced variation.

- There was some confusion as to the meaning of scales with respect to ecological organization. One participant felt that the use of levels would have been more clear.
- Adjectives used in the selection criteria to qualify statements (such as "helpful") were often difficult for participants to interpret.
- Some groups had difficulty with the definition of "high" and "low" with respect to natural variability and, therefore, this definition was generally used inconsistently within and among breakout groups.

Comments recorded by breakout groups regarding the selection criteria

The breakout groups were asked to record any comments that qualified their answer to a specific statement and/or a set of statements, such as "management relevance". These comments usually concerned why a certain park was not included in the applicable parks section or why the candidate vital sign was difficult to evaluate, given the selection criteria. Because many comments were recorded, resulting in a multiple-page report, a complete list of these comments is contained in Appendix H instead of in the body of this report.

<u>VITAL SIGNS MONITORING WORKSHOP-DAY 3</u>

Objectives

The objectives of the third day of the *Vital Signs Monitoring Workshop* were as follows:

- To present the results of the breakout groups' decisions on ranked list of vital signs
- To discuss options for organizing, into logical groups, vital signs whose data are generally collected simultaneously or, when combined, are more useful for interpreting results.
- Using a full suite of vital signs, to build a conceptual framework that integrates the diversity of spatial and temporal scales across the GRYN

Presentations, Breakout Group Exercises and Comments

Each participant was given a copy of the entire ranked list of candidate vital signs by score. Although many different kinds of reports could be produced and were discussed by the workshop planning team beforehand, an executive decision was made to distribute the ranked list by overall score. Many participants immediately voiced frustration with those candidate vital signs that ranked high and wanted to see the ranked list by resource area. This outcome was somewhat expected by the workshop planning team. A report listing the candidate vital signs by park and then by resource area was quickly produced and distributed. The distribution of this list was followed by a short presentation and comment section before participants were asked to participate in a breakout group exercise.

Presentation of the ranked list of vital signs

Cathie Jean, GRYN Program Manager

Cathie Jean congratulated the group on a job well done and commented on how nice it would have been to have one person contribute that one indicator that could tell us everything. Jean mentioned that the group did an excellent job of "cleaning up" the original list of proposed candidate vital signs by subsuming ninety candidate vital signs and adding twenty-one. Jean pointed out that nineteen vital signs received a "perfect" score, meaning that they met all of the selection criteria. She also pointed out that some groups interpreted the selection criteria differently and that this would be taken into consideration when choosing the final vital signs list. She reminded the participants that this ranked list was not the final list of vital signs to be monitored by the GRYN, but rather a tool to use in choosing the final vital signs. A complete ranked list of the candidate vital signs can be found in Appendix I of this report.

Comments

Many participants felt the need to share comments about the ranked list with the group as a whole. These comments were valuable in understanding the limitations of this exercise. The comments are summarized below:

- Participants felt that the candidate vital signs needed to be ranked relative to the other candidate vital signs in their resource areas. Participants were concerned that the GRYN would choose to monitor only those highly ranked vital signs without consideration of choosing a broad suite from many different resource areas.
- Participants felt it may be useful to have time to reconsider the candidate vital signs from their breakout group, as some believed that the scoring changed throughout the day and, thus, affected the overall result. Many groups who were rushed to finish by 5pm believed that those candidate vital signs scored later in the day could possibly have received better scores than they normally would have and believed that time for recalibration could have helped.
- Participants once again recognized the unevenness in specificity of the candidate vital signs. According to many experts, this caused an unevenness in scoring as well.
- Some participants included comments of papers that could be important and helpful in choosing vital signs. These included papers by Tom Hoeskstra of the Inventory and Monitoring Institute and the EPA's EMAP website.
- Concerns arose about the difference between vital signs that are drivers and those that are response variables.
- A comment was made that the vertebrate group did not look at specific habitat types, while the vegetation group did. This comment also follows that statement given by the vertebrate group on day two that vertebrate monitoring should be stratified by habitat.
- A participant brought up the fact that many of the highly ranked vital signs overlap, while also impacting other candidate vital signs.
- Someone also mentioned that there are many long-term datasets available, and a monitoring program should focus on what data can be used from these long-term datasets, even though they were not originally created to monitor the chosen candidate vital signs.
- Integration was a key component of many comments. Most participants felt that in order to have a comprehensive program, the GRYN must concentrate on integration both with other agencies as well as integrating the chosen vital signs into a coherent whole, including knowledge of the basic drivers of the systems.

Breakout group exercise

Options for organizing highly ranked vital signs into a coherent monitoring program

In order to bring some closure to the meeting, the workshop planning team devised a short exercise focusing on the creation of a conceptual framework that explains the spatial and temporal scales on which the candidate vital signs operate. To do this, the participants were asked to form into the same breakout groups that they had used during day two and were given overheads with a blank template of spatial and temporal scales. Participants were given the opportunity to draw the spatial and temporal scale of the candidate vital signs that they had ranked highly during day two on the overhead and to watch for aggregations of candidate vital signs along these given scales. Reproductions of the results of this exercise are contained in Appendix J of this report. Overall comments about the exercise follow.

Comments

- While some candidate vital signs may be sampled at a small scale, the effects of the results of this sampling can be amplified; thus, the candidate vital sign will have a wider applicability.
- The geology/geothermal group had to rescale the axes, as they were given a template made for ecological processes.
- The aquatics group also rescaled the axes to make the template more useful. A question was posed to the aquatics group about whether or not yearly changes in algal production is a reasonable way to assess nitrogen inputs. The answer given was that changes in diatom populations can be detected in time scales even shorter than one year.
- The air quality/climate group qualified the answers given by commenting that they focused on the measurement period and that the effects would be seen throughout the range of spatial and temporal scales given.
- One comment was made that the U.S. Forest Service starts monitoring with aerial detection and then "fills in" with groundwork.
- A participant commented that some vital signs will be good at detecting small-scale changes rather quickly, while others will be better at detecting changes across multiple scales. A mixture of these types of vital signs could produce the desired result of a comprehensive monitoring program.
- Someone also commented on the difficulty in integrating human-caused change with the vast array of natural variation one finds within ecosystems. The question was posed as to whether the monitoring program should be looking at human impacts or having the ecosystems unimpaired for future generations. In order to accomplish this, goals and objectives need to be set; then, the monitoring objectives that the GRYN establishes can define a meaningful level of change and how best to detect such a change.

CONCLUSIONS

In conclusion, the *Vital Signs Monitoring Workshop* hosted by the GRYN was a success. Although participants had concerns with the wording and interpretation of the selection criteria, as well as the ranked list of candidate vital signs, the workshop planning team agreed that creating a framework that allowed a large group of experts to come together and offer knowledge and insight into the proposed list of vital signs was extremely useful and productive. The participants successfully applied an objective set of criteria to a long list of proposed candidate vital signs. The criteria used were a balance of complex ideas and a simplified ranking system. Because of among-group variations in interpretation of the criteria, the results are best reviewed within groups.

In order to aid future Networks with their vital signs scoping workshops, the GRYN has developed a short list of lessons learned from the *Vital Signs Monitoring Workshop*:

- Doing a "trial run" of the selection criteria and a proposed candidate vital sign will help everyone involved to understand the depth of knowledge and consideration that is needed to answer the given questions
- Sending out information that will be used during the workshop would be helpful to those who have time for preparatory work
- Spending time deciding on the level of specificity for the candidate vital signs names and tailoring the names to this level before the workshop could eliminate some of the confusion seen at the GRYN workshop
- Making sure that participants are given a chance to review the schematic and narrative conceptual models beforehand would allow for a greater understanding of the process as well as give participants a chance to express concerns with the results of these processes with the model authors
- The first and second weeks of May are generally poor times to invite academic and agency scientists to travel for a meeting
- Given more time, many of these concerns would probably have been addressed by the GRYN.

Despite the set-backs, the GRYN now has a defensible list of candidate vital signs based on sound scientific advise from experts in many different fields from which it can take on the task of creating a comprehensive and integrative monitoring program. By all accounts, the participants who took part in this process, although frustrated at times, were always forthcoming with helpful comments about the process and the specific candidate vital signs, as well as having a high level of respect and praise for their colleagues in this exercise. The outcome of this meeting will be of particular interest to those Networks that are just beginning this process. The workshop planning team and the staff of the GRYN expresses a wealth of gratitude toward all who participated and hopes that everyone will stay tuned for our next steps!

ACKNOWLEDGEMENTS

The Greater Yellowstone Inventory and Monitoring Network wishes to extend a sincere thank you to those who made this workshop possible. The USGS-Northern Rocky Mountain Science Center is the campus host for the GRYN and, therefore, serves a central role in the GRYN's ability to use campus resources. A partnership through the Big Sky Institute at Montana State University allowed us to provide refreshments for guests through MSU Catering. We would like to thank the MSU Foundation for allowing us the use of their Great Room for our evening social. We would like to express our gratitude for the facilitation services provided by Michele Tae (throughout the workshop series) and Nancy Budge (for this workshop). Peggy Herzog was the scribe for the workshop series. A big thanks goes out to Chad Jacobson, Cartographic Technician for the GRYN, who became the interim data manager for the duration of the conference. Finally, many thanks to the GRYN's student employee, Sarah Stehn, who was extremely helpful in the days before the workshop, as well as aiding Chad with the data entry during the evening on day two of the workshop.

APPENDICES-TABLE OF CONTENTS

Appendix A-Workshop Agenda

Greater Yellowstone Network Vital Signs Monitoring Workshop

Agenda

May 6-8, 2003
Ballroom C, Strand Union Building
Montana State University

Overall Workshop Objective:
To apply priority setting to a list of vital signs to be monitored as a means for determining the long-term ecosystem health of the parks of the Greater Yellowstone Network

May 6

Day 1 Objectives:

1. To create a shared understanding of the NPS I&M Program and the Greater Yellowstone Network
2. To inform participants of the process used to identify candidate vital signs
3. To create an informal, open-forum discussion of the posted conceptual models as part of an evening social hour

12:30	**Participants Arrive, Joseph May Ballroom C, Strand Union Building** *Sign-in/registration*
1:00	**Welcome, Opening Comments** Tom Olliff, Chief of Resources, Yellowstone National Park
1:10	**Statement of Meeting Goals and Agenda Review** Cathie Jean, Program Manager, Greater Yellowstone Network
1:25	**Introduction to the National Park Service Inventory & Monitoring Program** Steve Fancy, National I&M Program Coordinator
	Greater Yellowstone Network Vital Signs Monitoring Plan Cathie Jean, Program Manager, Greater Yellowstone I&M Network
2:00	**Variability in Natural Systems and Monitoring Considerations** Duncan Patten, Research Professor, Montana State University
2:30	**Break**
2:45	**The Role of Conceptual Models in Choosing Vital Signs**

- Overview of Conceptual Models, Glenn Plumb, Supervisory Wildlife Biologist, Yellowstone National Park
- Riparian and Wetland Ecosystem Model, Duncan Patten, Research Professor, Montana State University
- Terrestrial Ecosystem Model, Dan Tinker, Assistant Professor, University of Wyoming
- Aquatic Ecosystem Model, Bob Hall, Assistant Professor, University of Wyoming

3:45 **Workshop Objectives and Instructions**
Michele Tae, facilitator
- Breakout group objectives
- Explanation of Selection Criteria
- Roles of Moderators, Facilitators and Participants
- Participant Assignments and Meeting Locations

5:00 **Adjourn**

6:30 ****Social Hour**, MSU Alumni Foundation, 1501 S. 11th Ave.**
**Participants are encouraged to critique the conceptual models and discuss candidate vital signs with the authors of the conceptual models.

May 7

Day 2 Objectives:

1. To apply the selection criteria from the decision support system to each candidate vital sign in the topic area and provide results to the decision support system manager by 5:00 pm
2. To document comments related to the scoring decisions that will be incorporated into a report for the Technical Committee and Science Committee

8:00 **Groups Convene**
*Please use the attached map of the Strand Union Building and breakout group room assignments to find your breakout room for the day.

12:00 **Luncheon, Joseph May Ballroom C, Strand Union Building**

5:00 **Adjourn**

May 8

Day 3 Objectives:

1. To present the results of the breakout groups' decisions on ranked list of vital signs
2. To discuss options for organizing, into logical groups, vital signs whose data are generally collected simultaneously or, when combined, are more useful for interpreting results.
3. Using a full suite of vital signs, to build a conceptual framework that integrates the diversity of spatial and temporal scales across the network.

8:00 **Groups Convene, Joseph May Ballroom C, Strand Union Building**
Welcome and Comments
Michele Tae, facilitator

8:15 **Presentation of the Ranked List of Vital Signs**
Cathie Jean, Program Manager

8:30 **Part 1 Integration Exercise: Options for Organizing Highly Ranked Vital Signs into Logical Groups**
Michele Tae, facilitator
Glenn Plumb, Supervisory Wildlife Biologist, Yellowstone National Park

9:45 **Break**
** For those participants whose flights depart around noon or 1pm, a shuttle will be leaving from the Strand Union Building to take you to the airport following break.

10:00 **Part 2 Integration Exercise: Building a Conceptual Framework that Integrates a Full Suite of Vital Signs**

11:15 **Results of Conceptual Framework Exercise:**
Michele Tae, facilitator
Glenn Plumb, Supervisory Wildlife Biologist, Yellowstone National Park

11:45 **Wrap-up and adjournment**
** For those participants with flights later in the afternoon, a shuttle will be leaving from the Strand Union Building to take you to the airport at noon.

APPENDIX B-SELECTION CRITERIA WORKSHEET

VITAL SIGN:
PRIMARY RESOURCE:
Secondary Resource:

Parks that this Vital Sign applies to:
YELL GRTE BICA

VITAL SIGN CRITERIA	Yes	No	Comments
Ecological Relevance			
• The candidate vital sign has high ecological importance with a demonstrated linkage between the vital sign and the ecological structure or function that it is supposed to represent, based on a conceptual model and/or supporting ecological literature	❍	❍	
• The candidate vital sign provides relevant information that is applicable to multiple scales of ecological organization	❍	❍	
Response Variability			
• The candidate vital sign responds to ecosystem stressors in a predictable manner with known statistical power	❍	❍	
• The candidate vital sign is anticipatory and is sensitive enough to stressors to provide an early warning of change	❍	❍	
• The candidate vital sign has low natural variability and has high signal-to-noise ratio (e.g. low error)	❍	❍	
Management Relevance			
▪ The candidate vital sign is stated in specific park management goals, GPRA goals, or Business Plan standards.	❍	❍	
▪ There is a demonstrated, direct application of candidate vital sign measurement data to current key management decisions or for evaluating past management decisions	❍	❍	
Feasibility of Implementation			
• The candidate vital sign's cost of measurement is not prohibitive	❍	❍	
• Impacts of measuring the candidate vital sign meet NPS standards	❍	❍	
• The candidate vital sign is relatively easy to measure and has measurable results that are repeatable with different personnel	❍	❍	
Interpretation and Utility			
• The response of the candidate vital sign can be distinguished between natural variation and anthropogenic impact-induced variation	❍	❍	
• The candidate vital sign is helpful in identifying the causal mechanism of an ecological response	❍	❍	
• Historic databases and baseline conditions for the candidate vital sign are already known	❍	❍	

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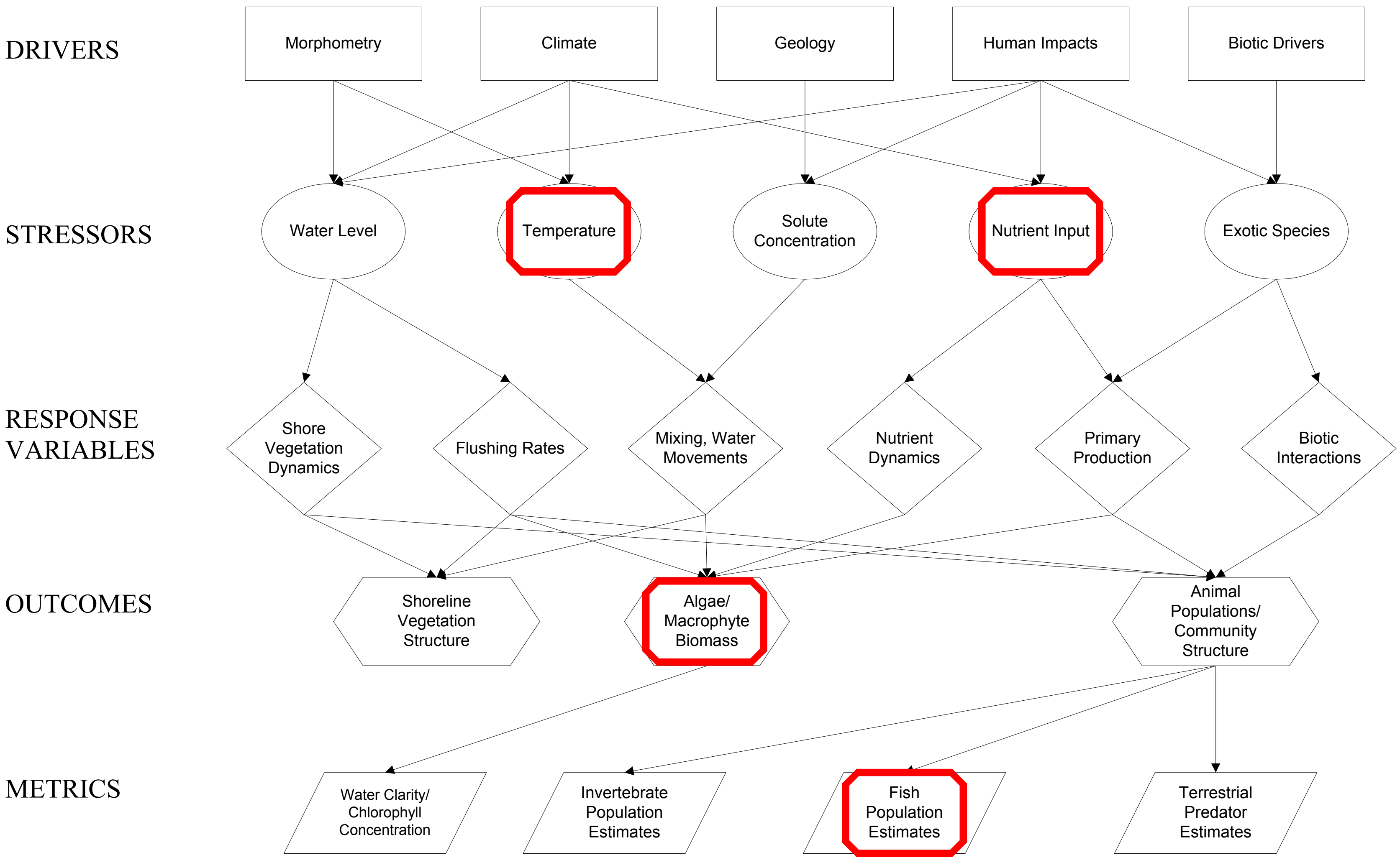
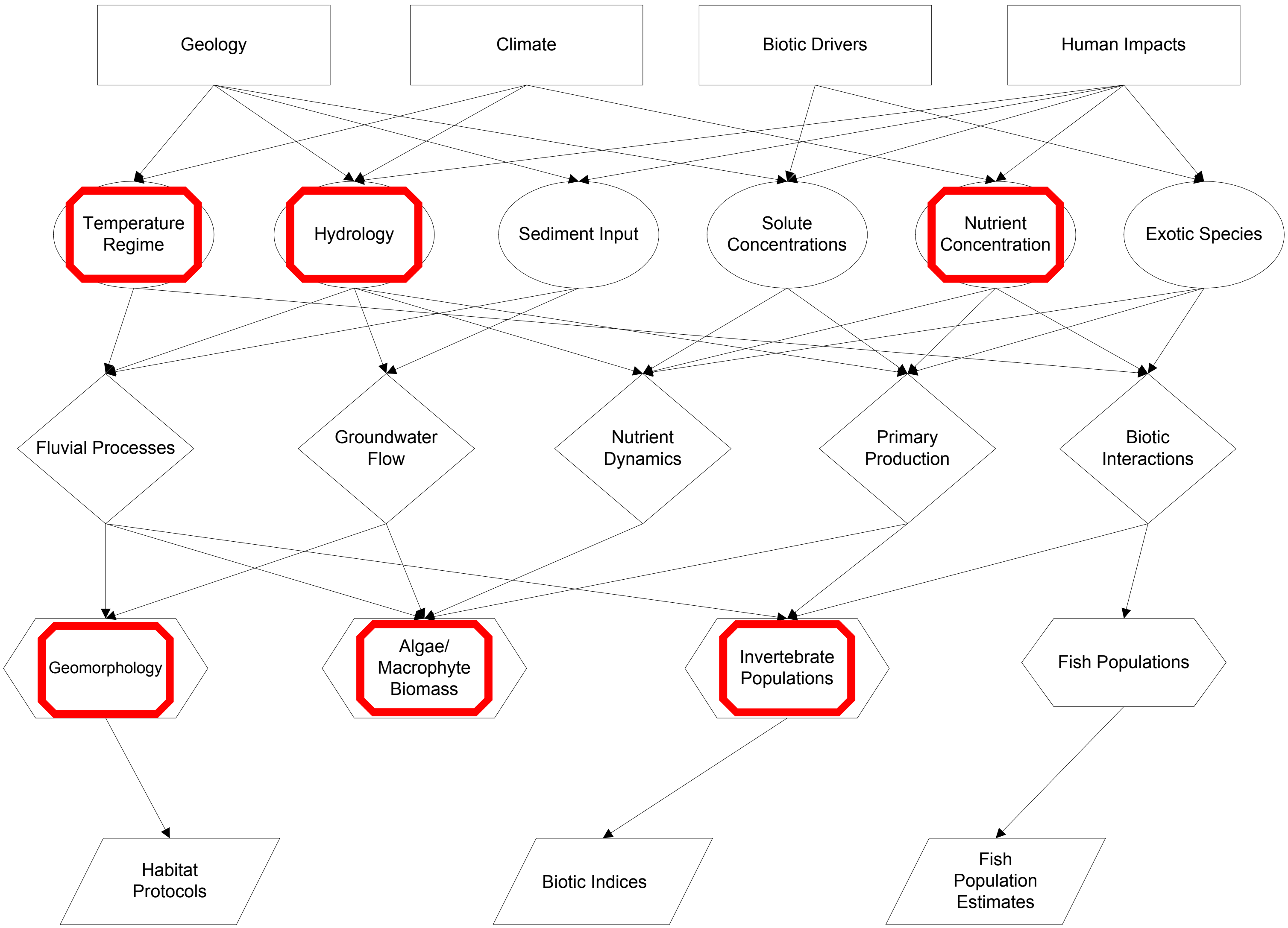
Appendix D-Schematic Ecosystem Conceptual Models

**Please note: those polygons highlighted in red represent proposed candidate vital signs chosen by the authors.

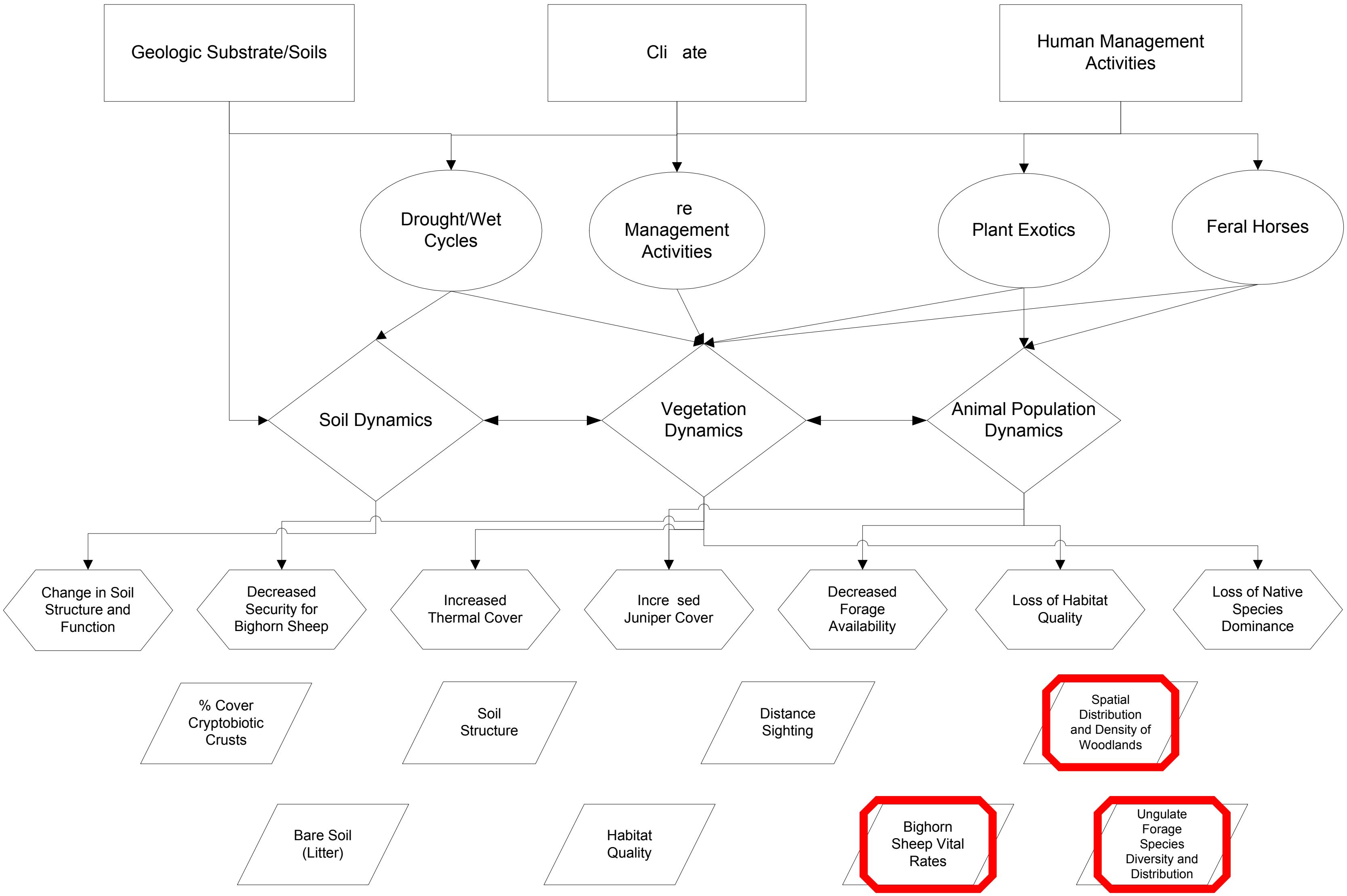
Lake Model-Bob Hall



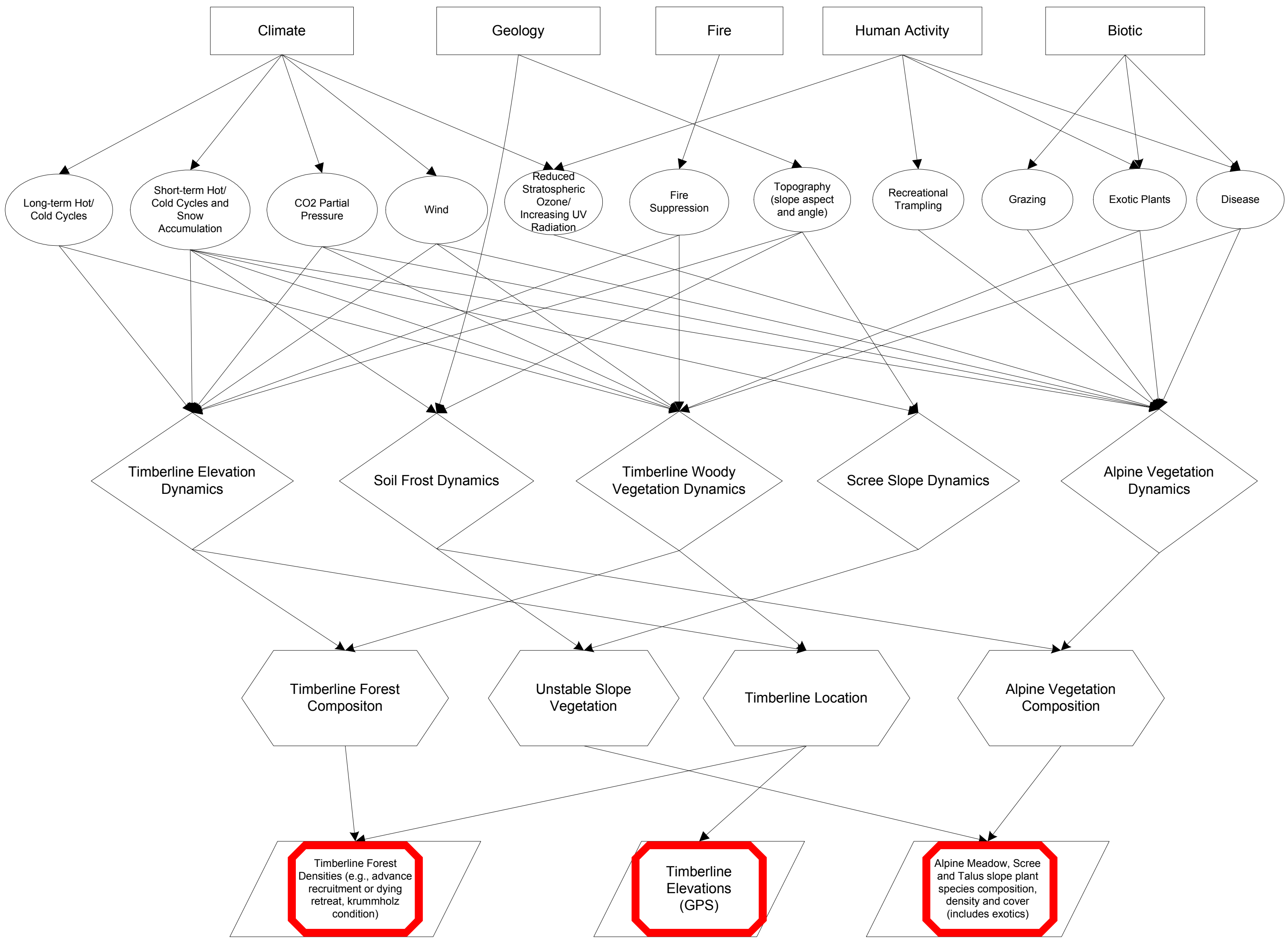
River Model-Bob Hall



Dry Woodland Model-Cathie Jean

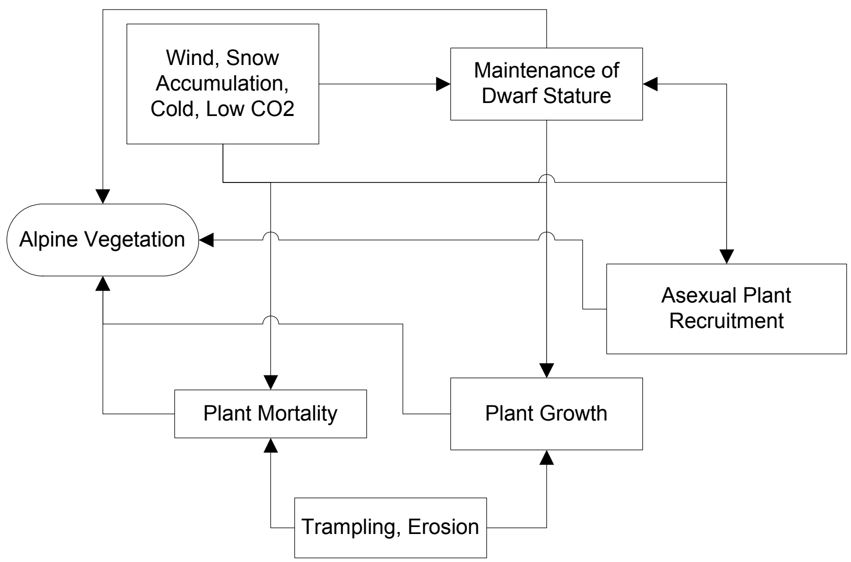


Alpine and Timberline Model-Duncan Patten

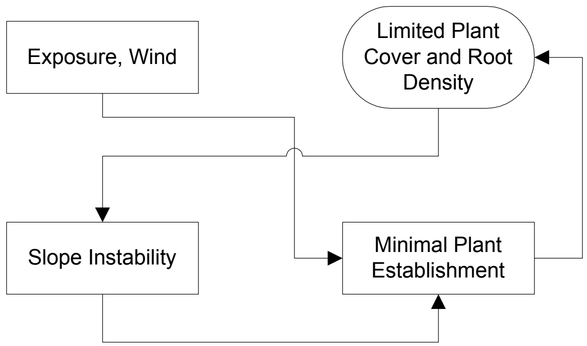


Alpine and Timberline Submodels-Duncan Patten

Alpine Vegetation

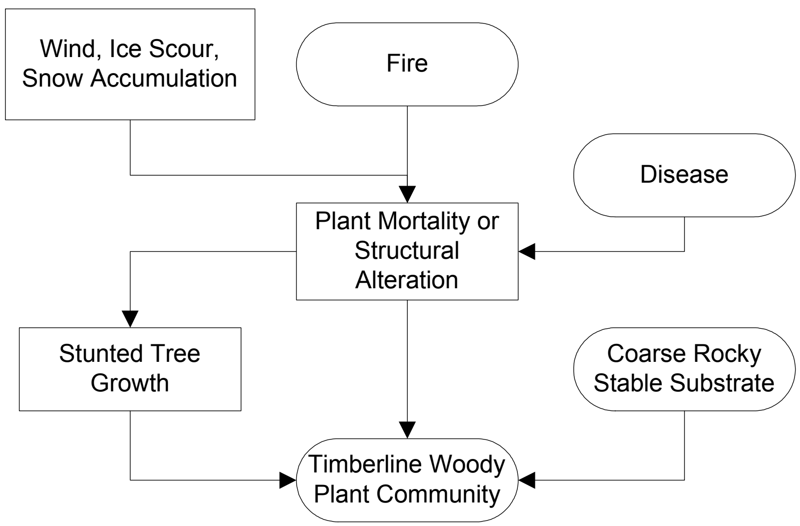


Scree Slope Dynamics

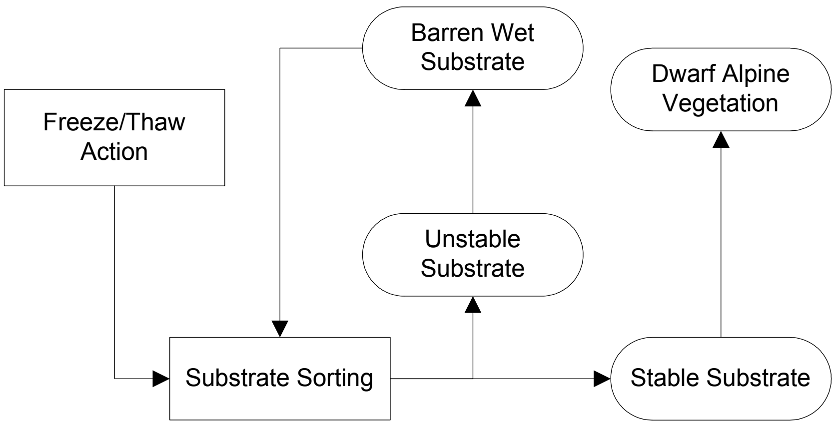


Alpine and Timberline Submodel (continued)-Duncan Patten

Timberline Woody Vegetation

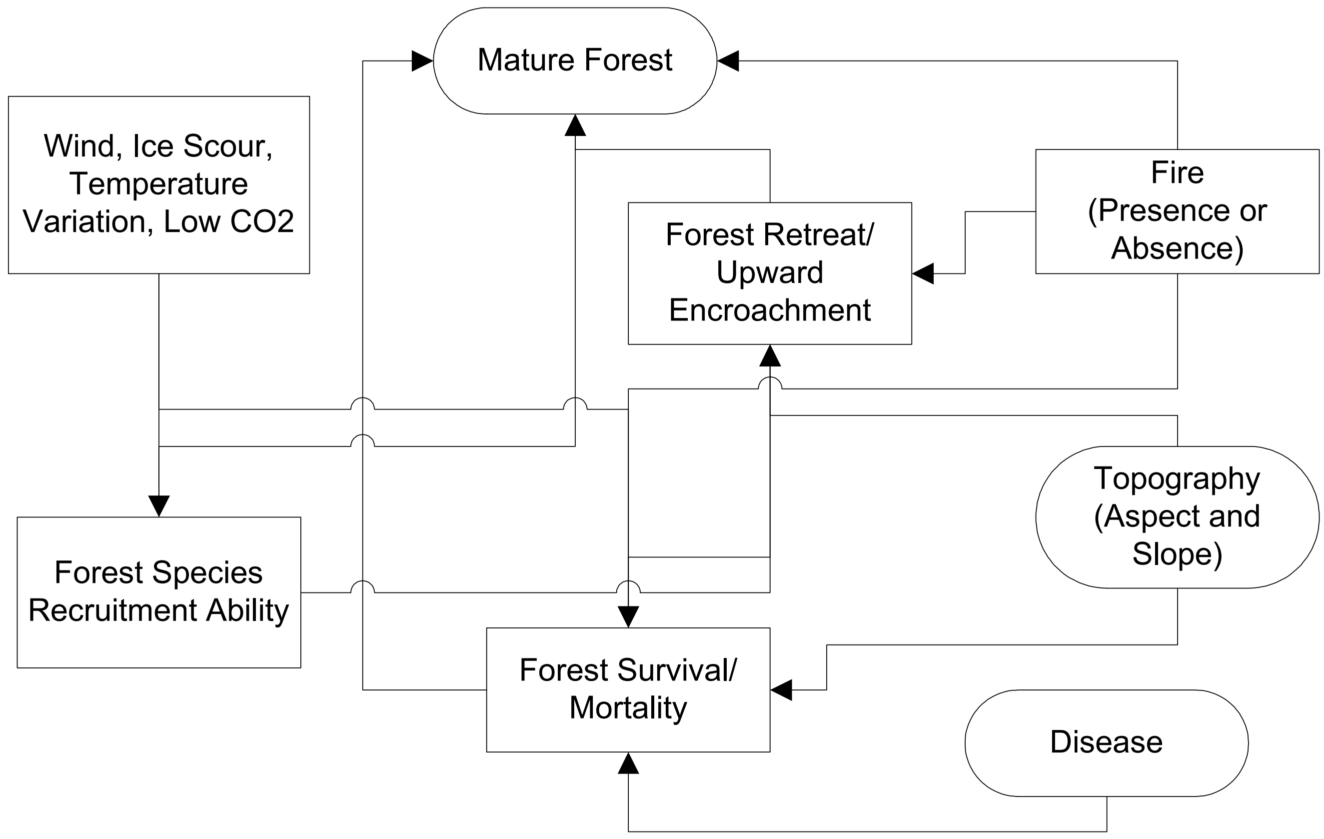


Soil Frost Dynamics

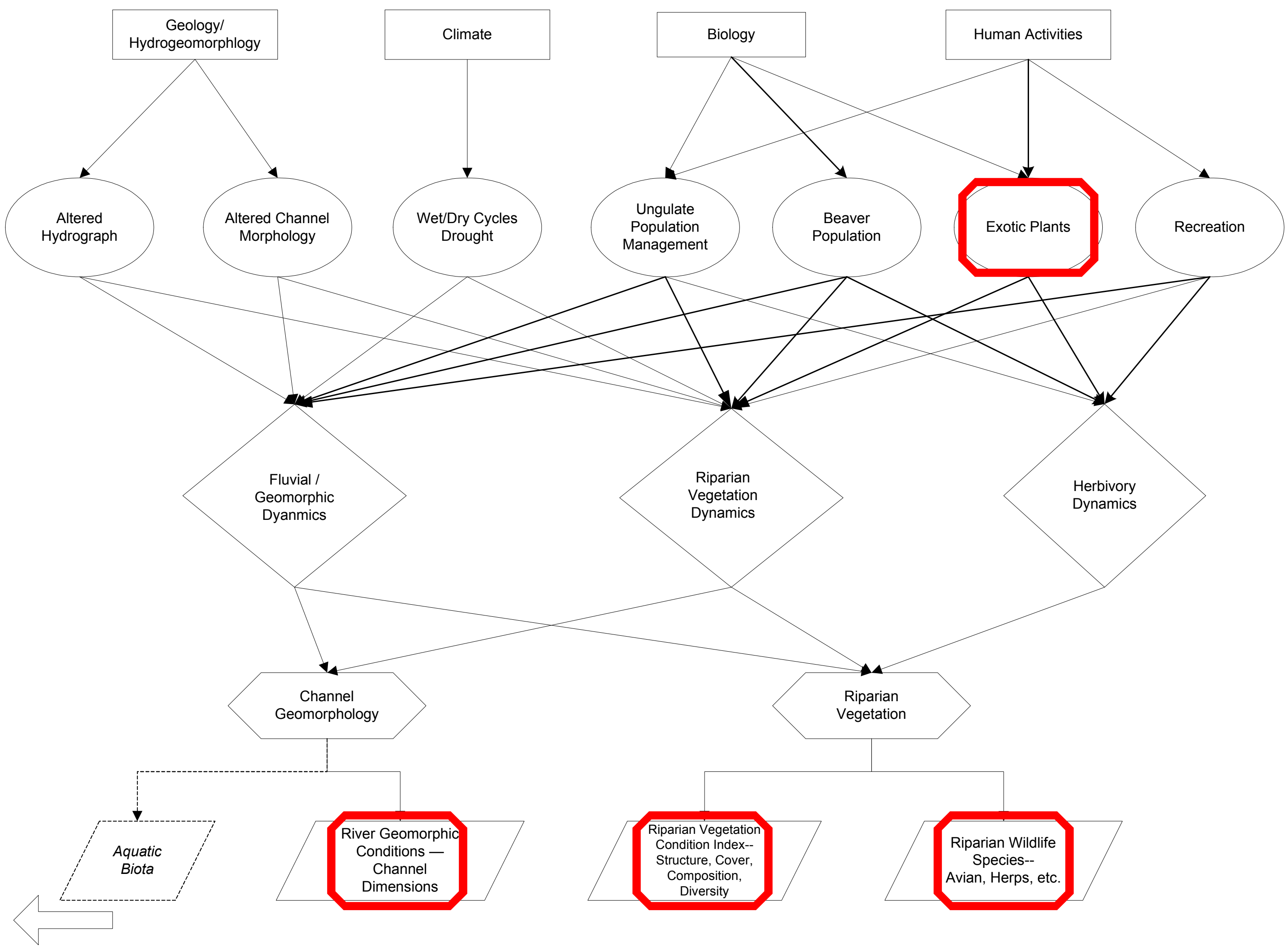


Alpine and Timberline Submodels (continued)-Duncan Patten

Timberline Elevation

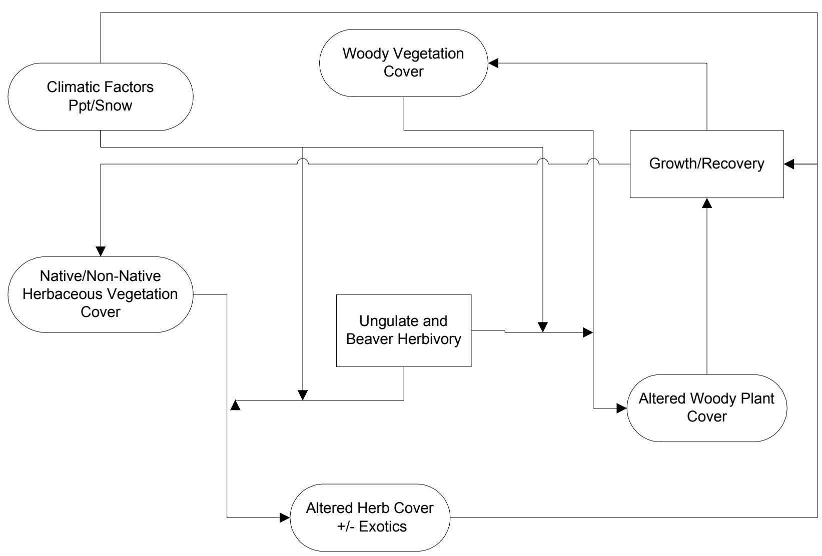


Riparian Model-Duncan Patten

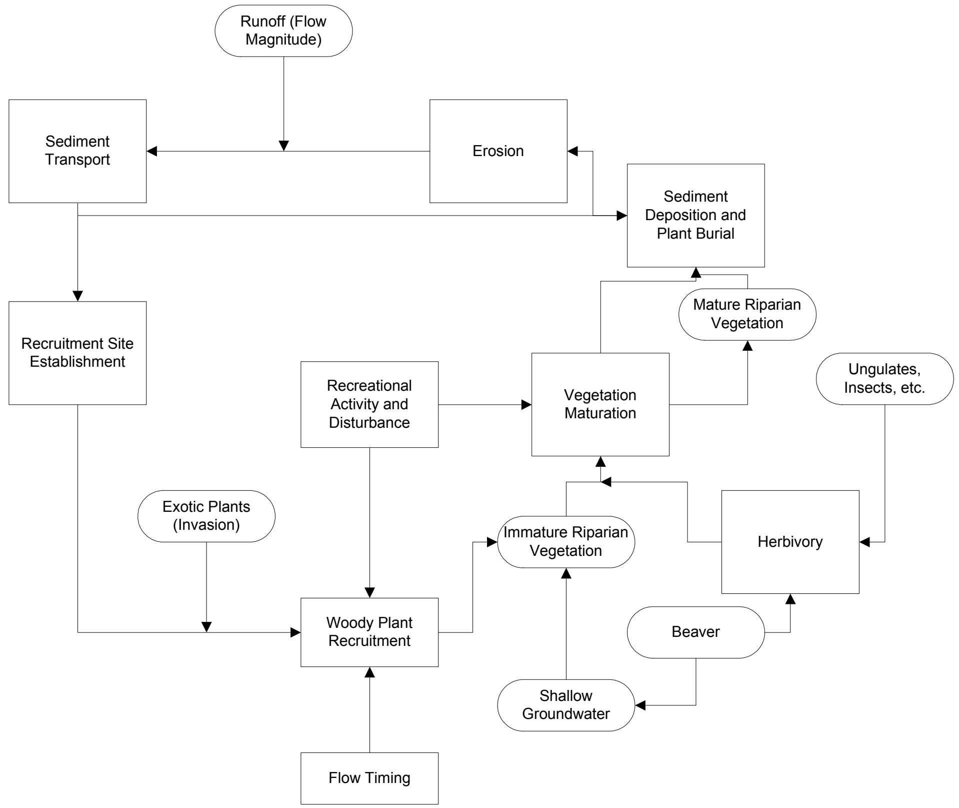


Riparian Submodels-Duncan Patten

Herbivory Dynamics

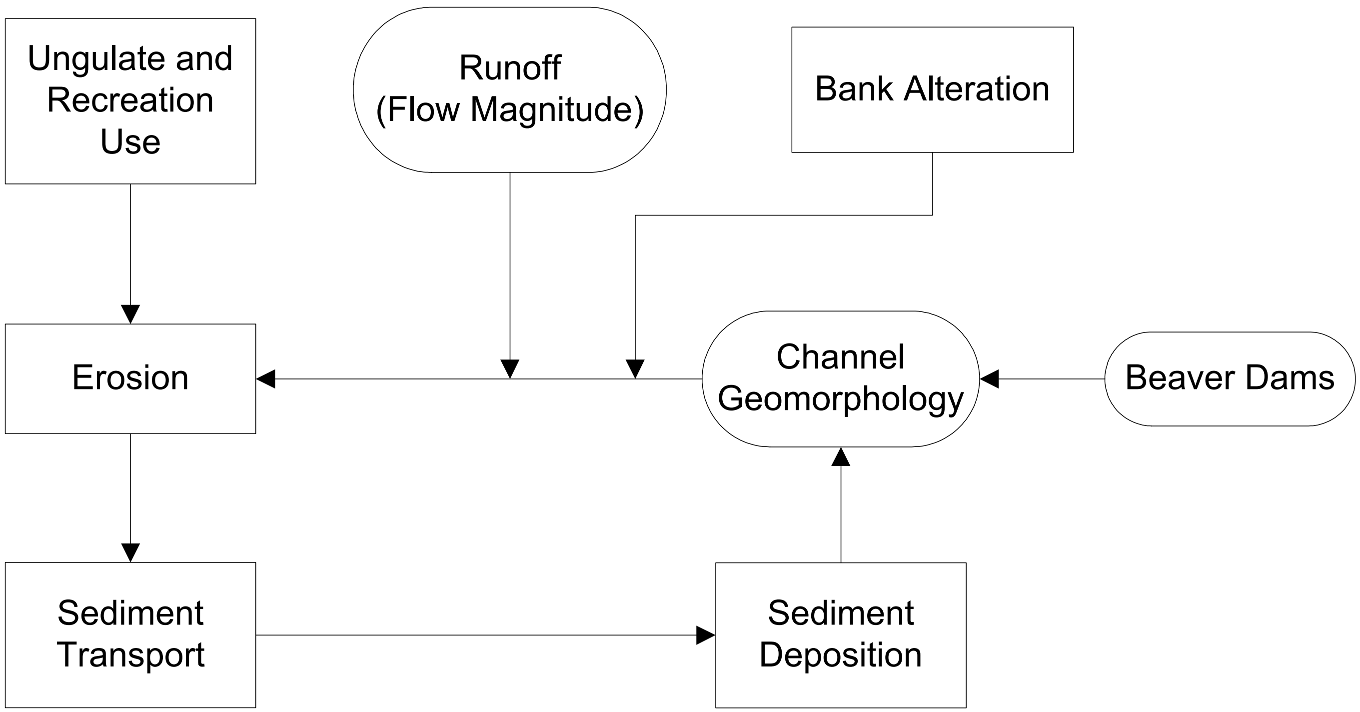


Riparian Vegetation Dynamics

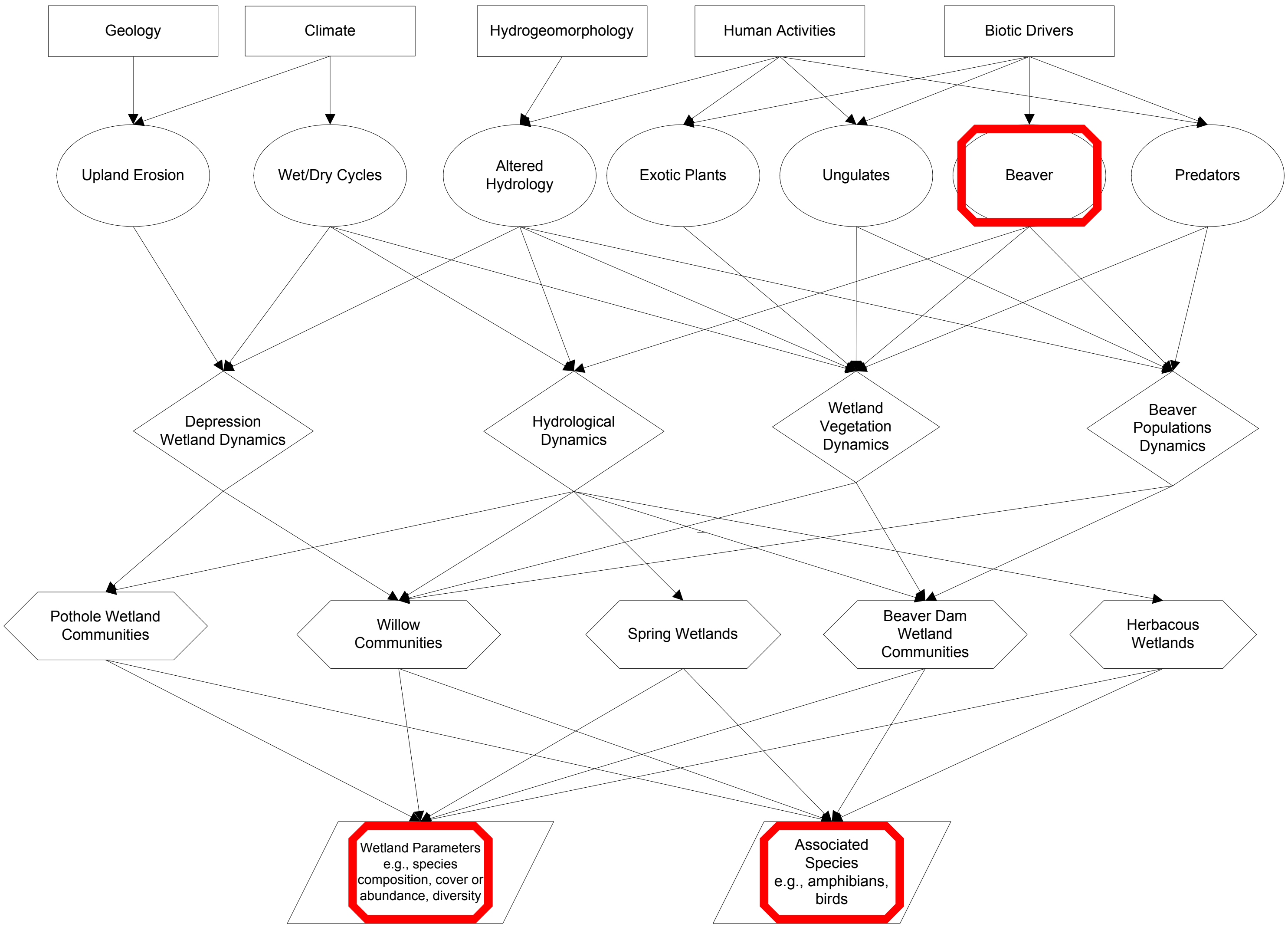


Riparian Submodels (continued)-Duncan Patten

Fluvial Geomorphology Dynamics

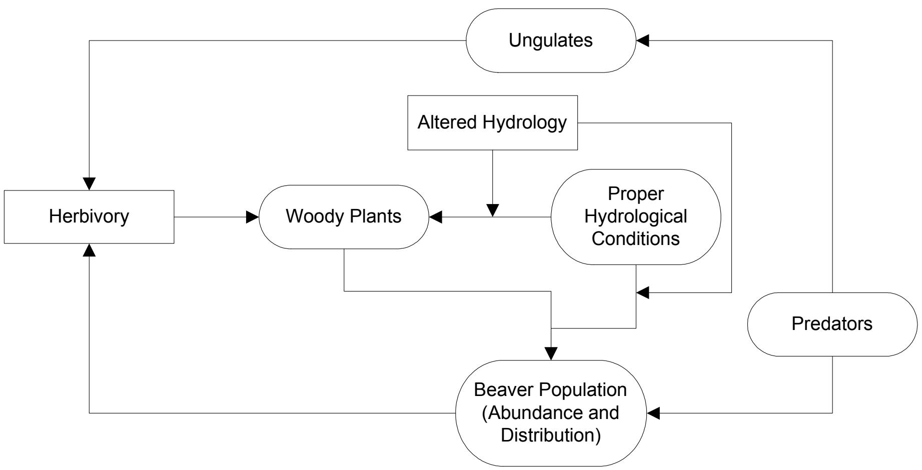


Wetland Model-Duncan Patten

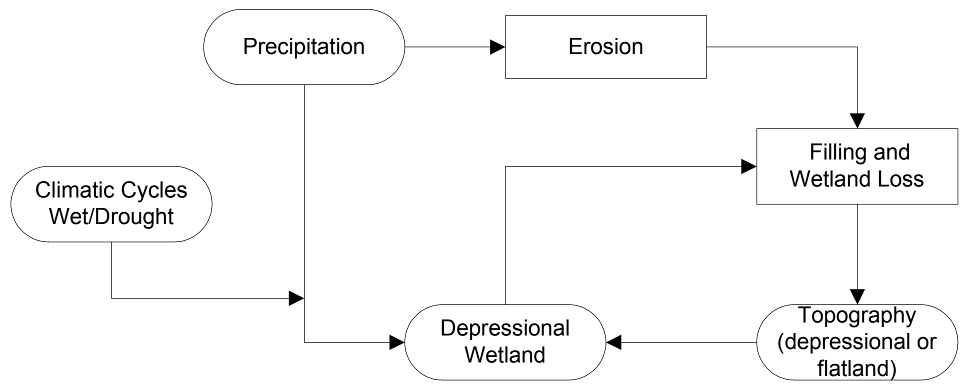


Wetland Submodels-Duncan Patten

Beaver Population Dynamics

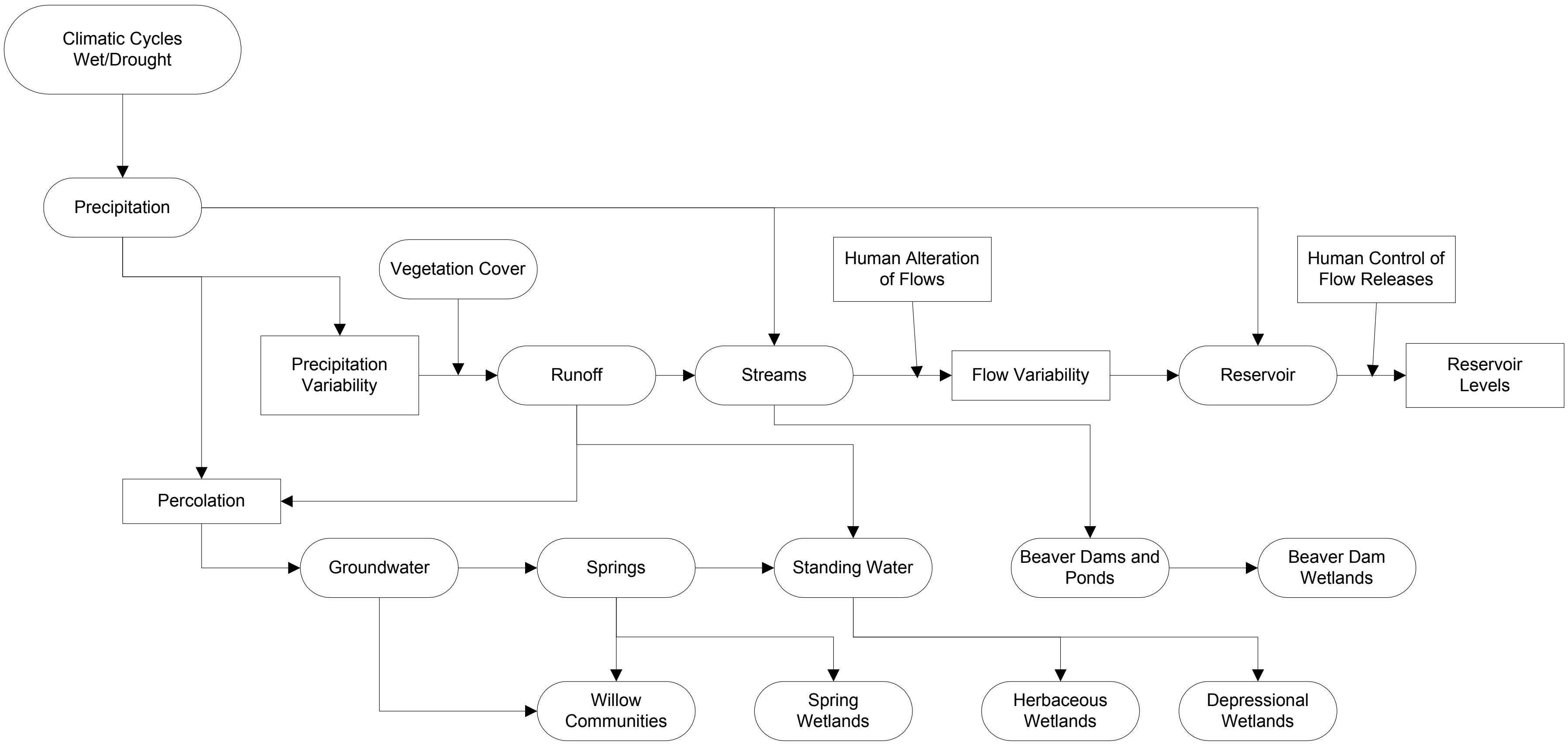


Depressional Wetland Dynamics



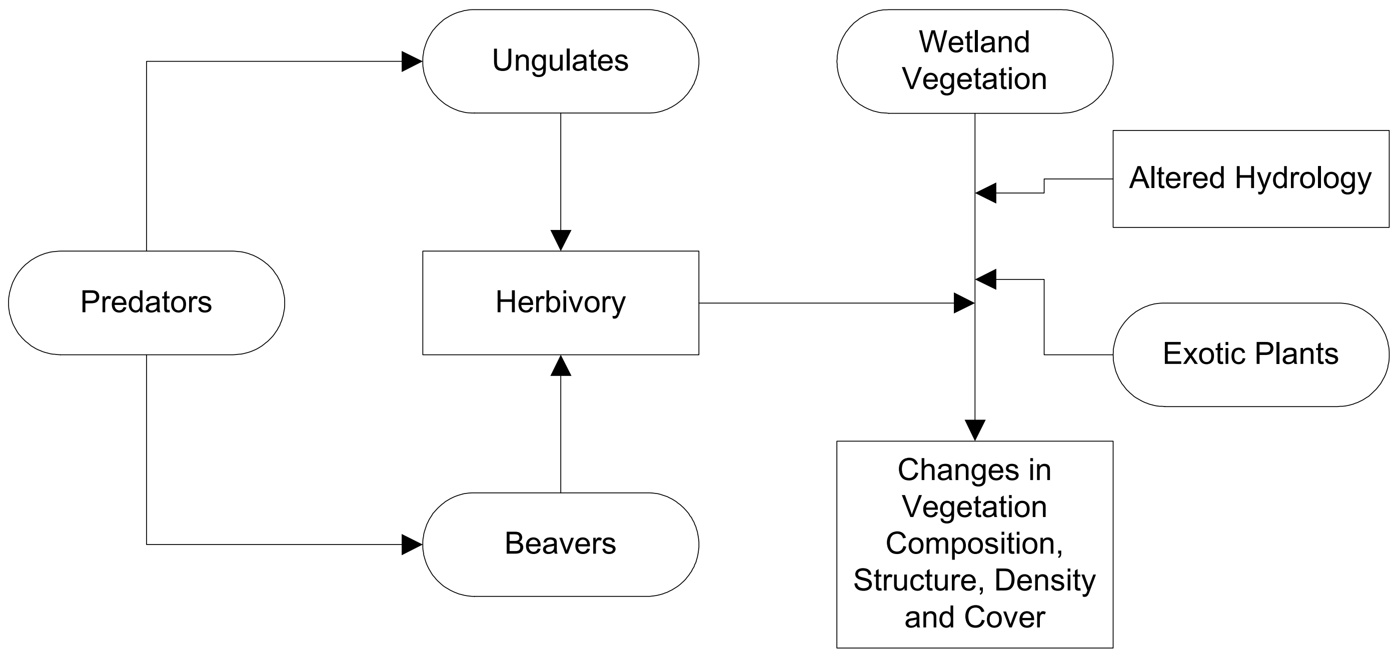
Wetland Submodels (continued)-Duncan Patten

Hydrology Dynamics

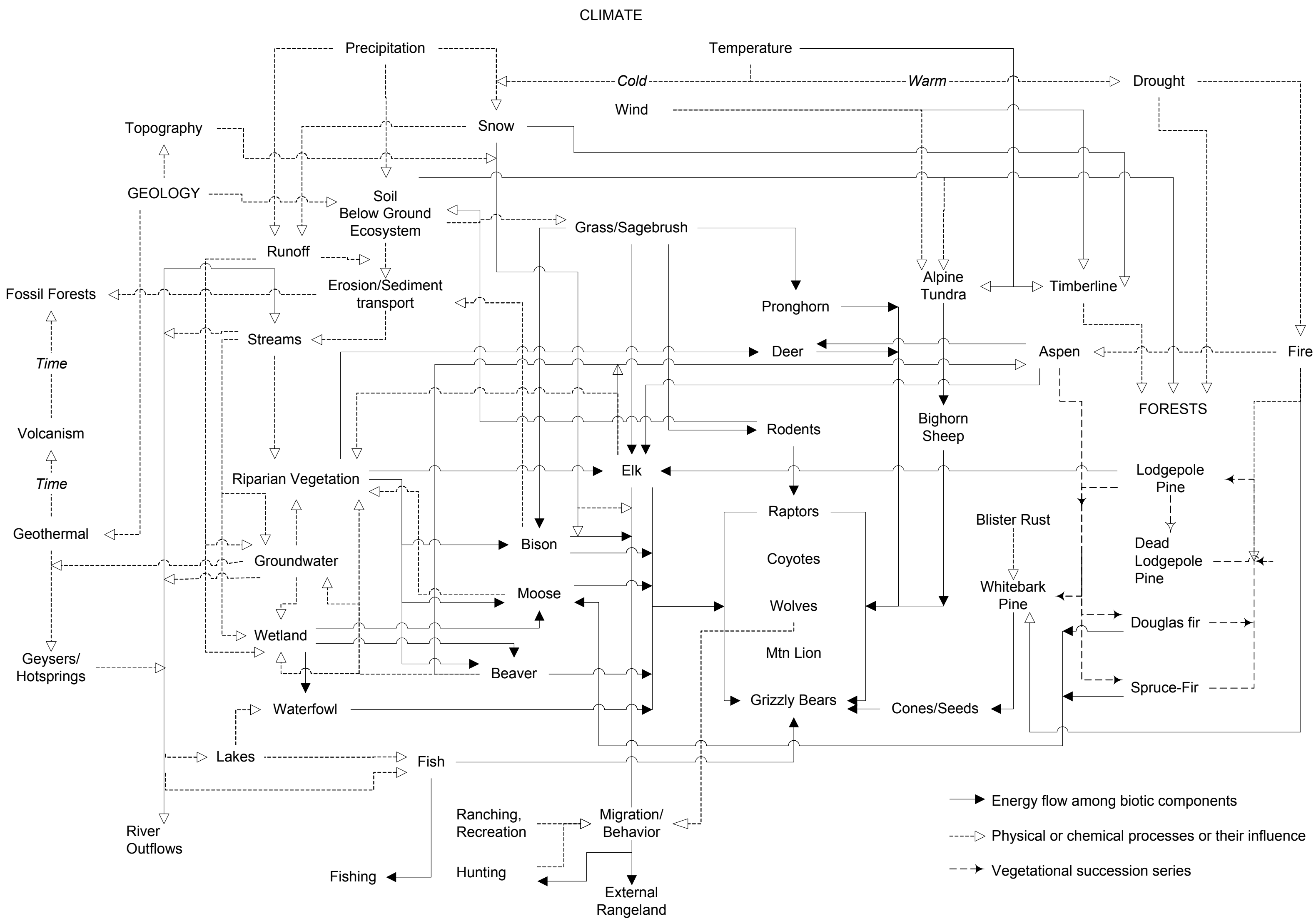


Wetland Submodels (continued)-Duncan Patten

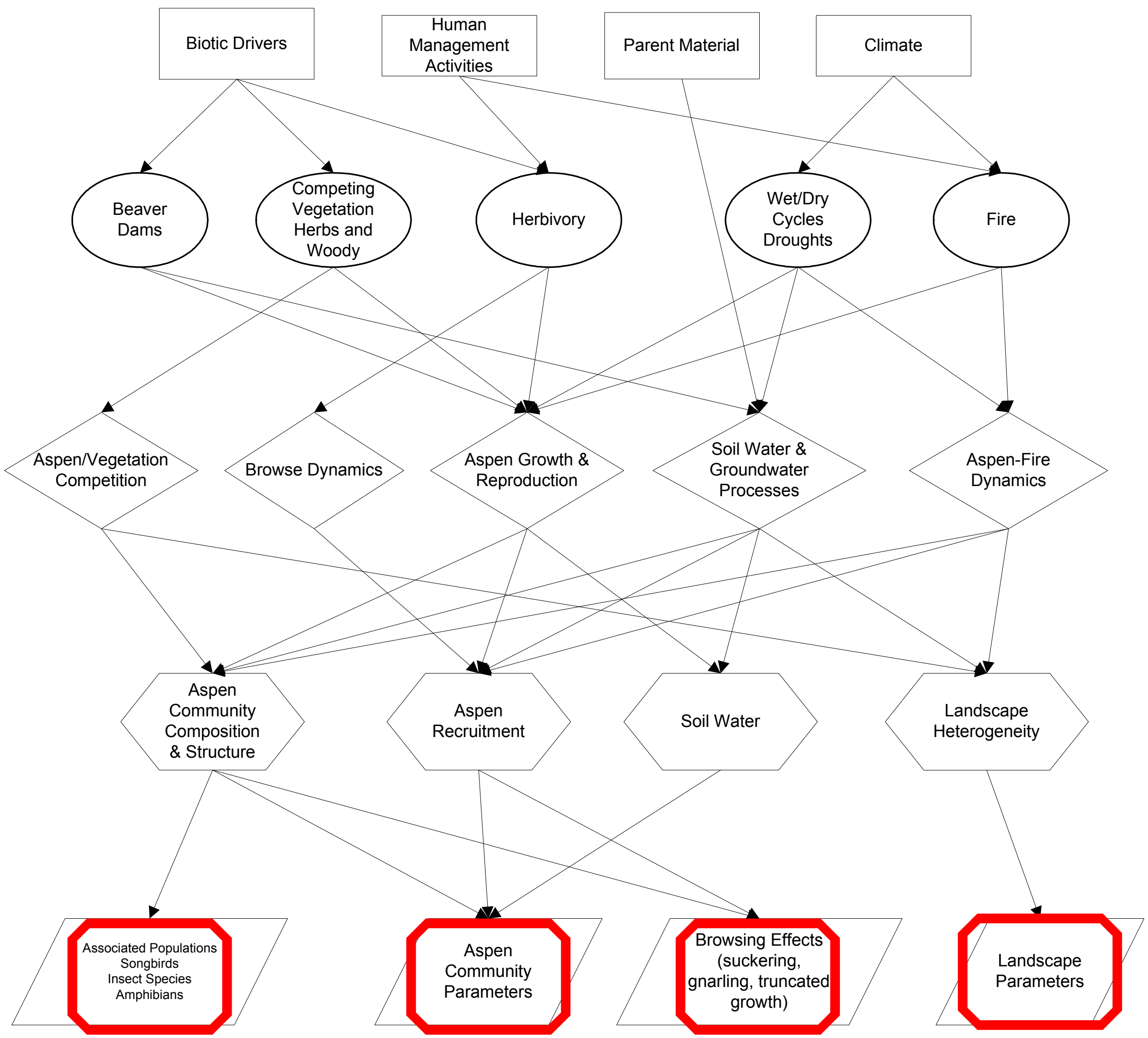
Wetland Vegetation Dynamics



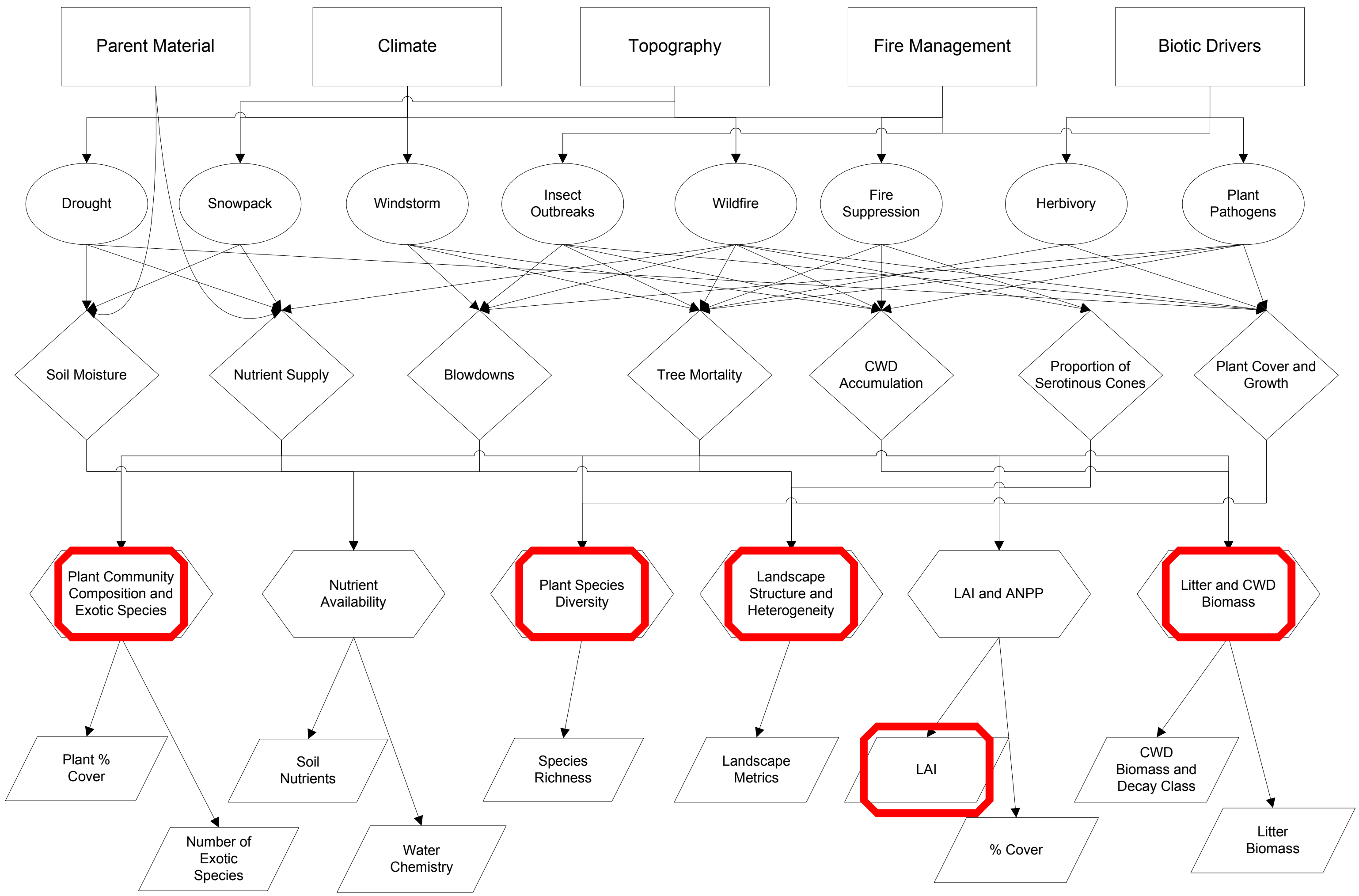
Yellowstone National Park Model-Duncan Patten



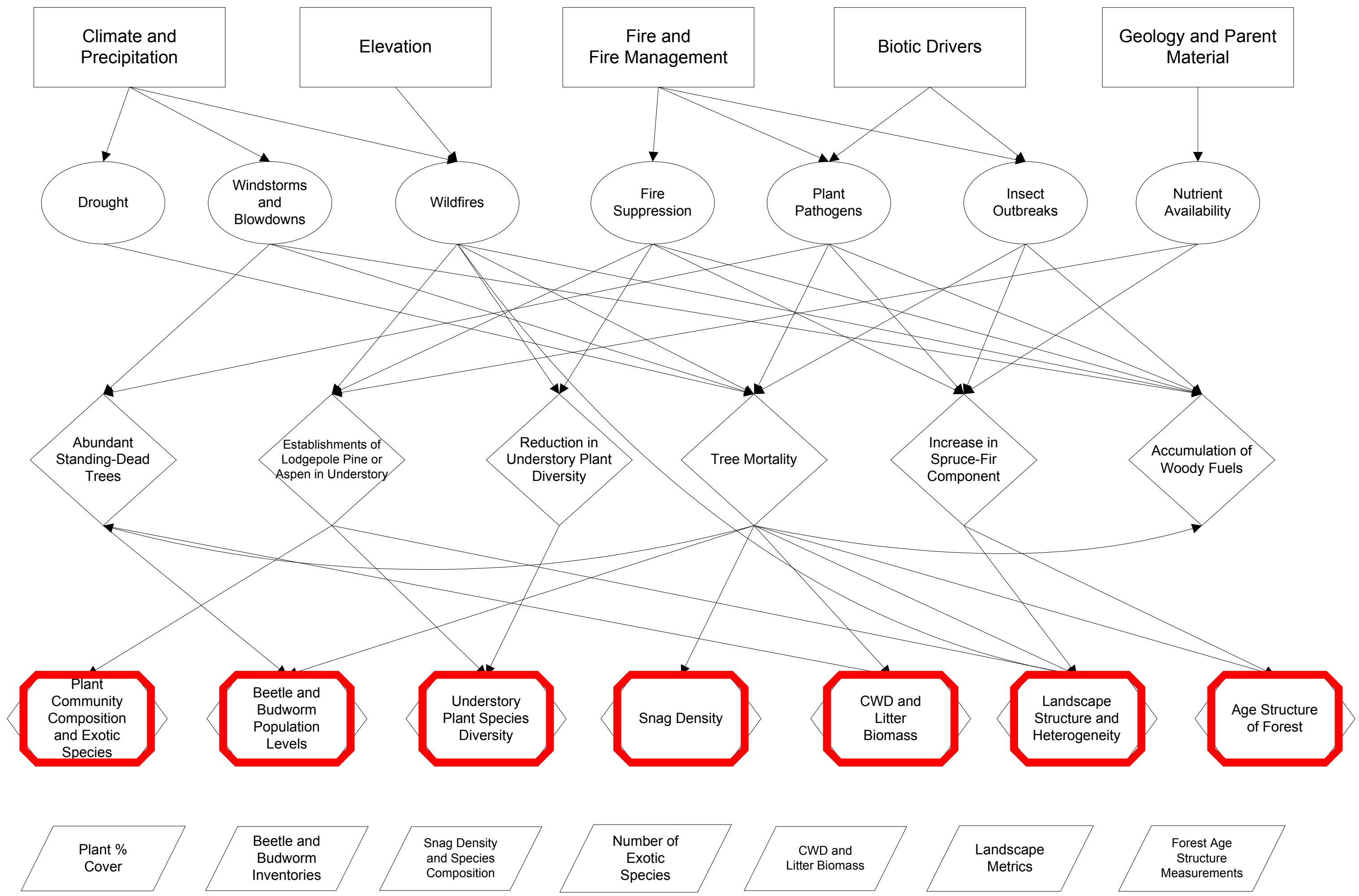
Aspen Model-Duncan Patten and Dan Tinker



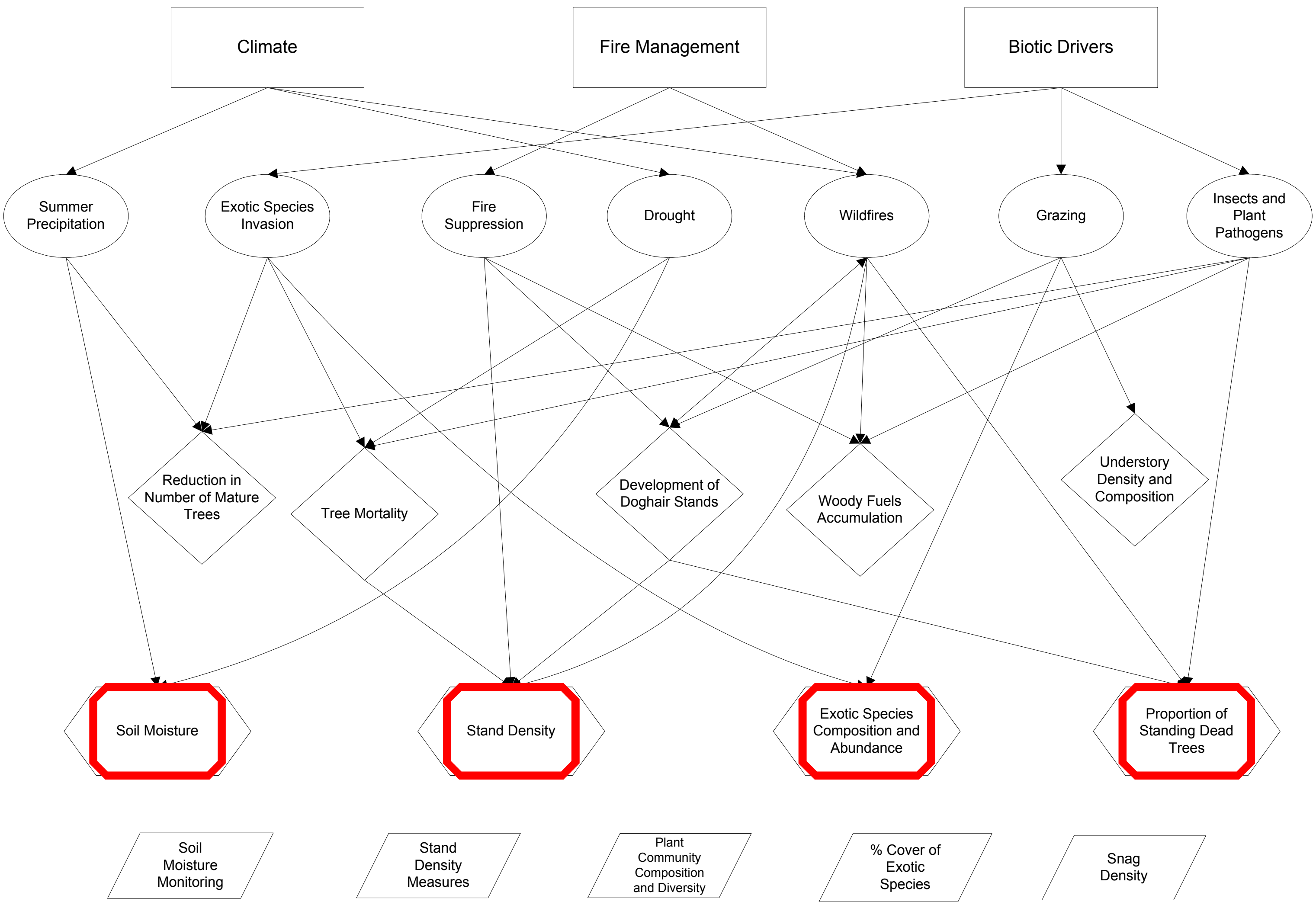
Lodgepole Pine Model-Dan Tinker



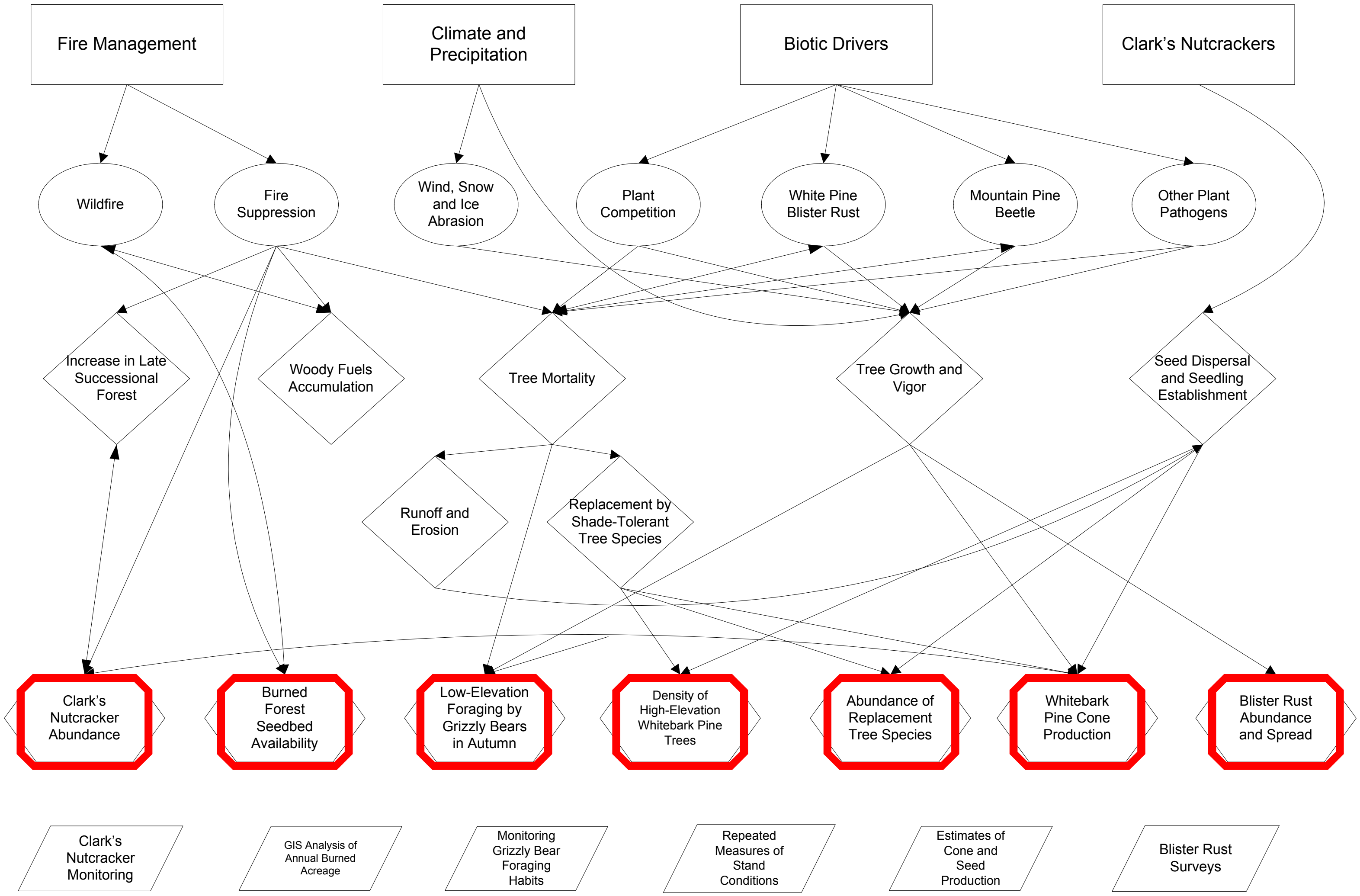
Mixed Conifer Model-Dan Tinker



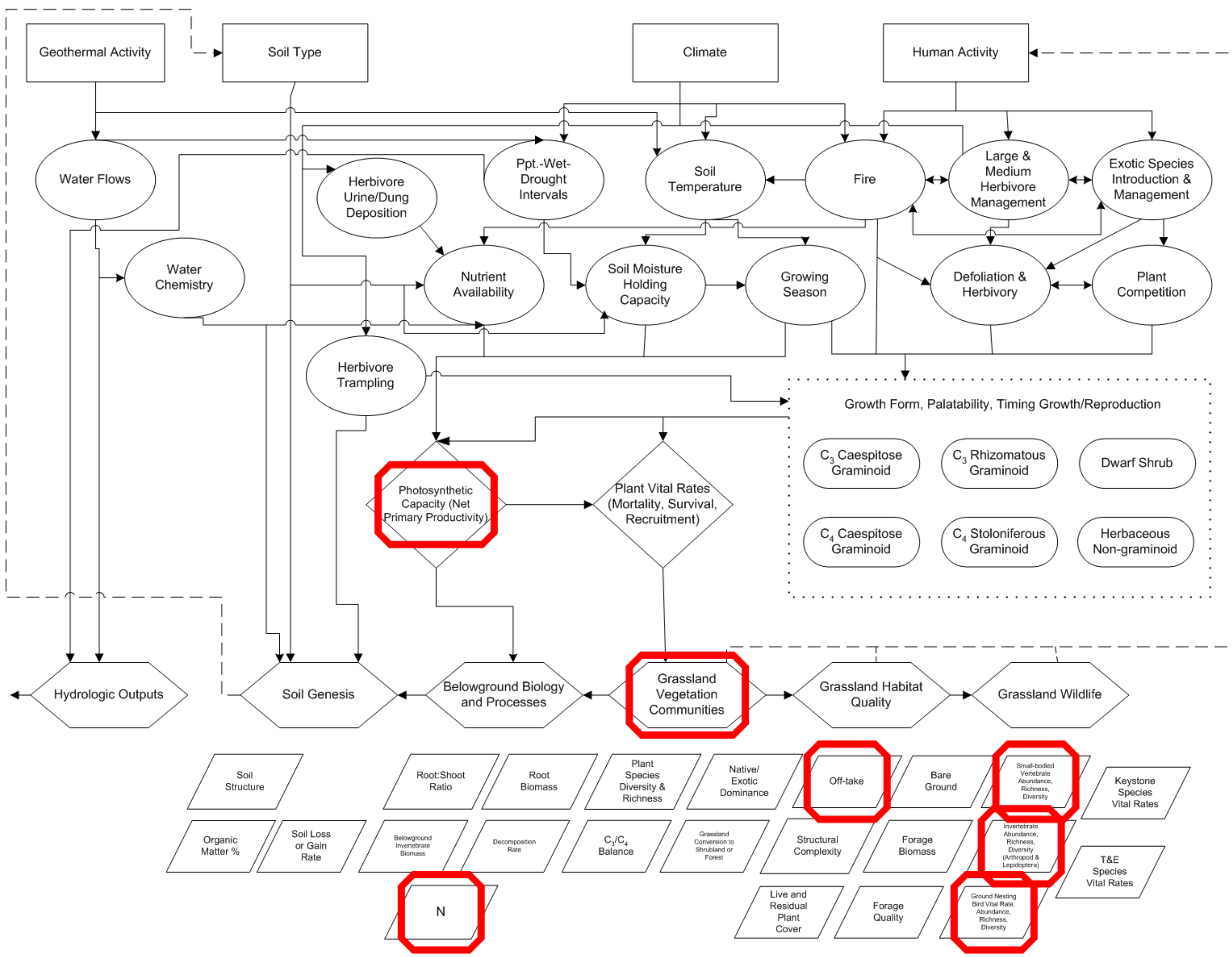
Ponderosa Pine Model-Dan Tinker



Whitebark Pine Model-Dan Tinker

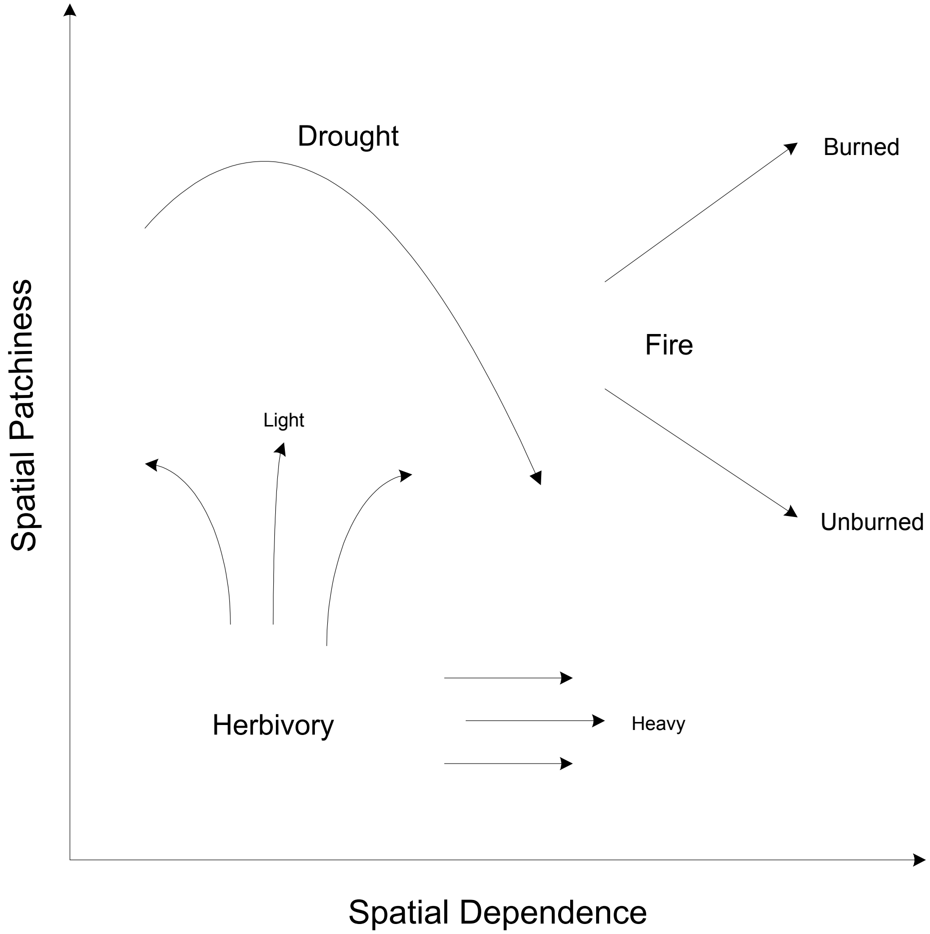


Grassland Model-Glenn Plumb



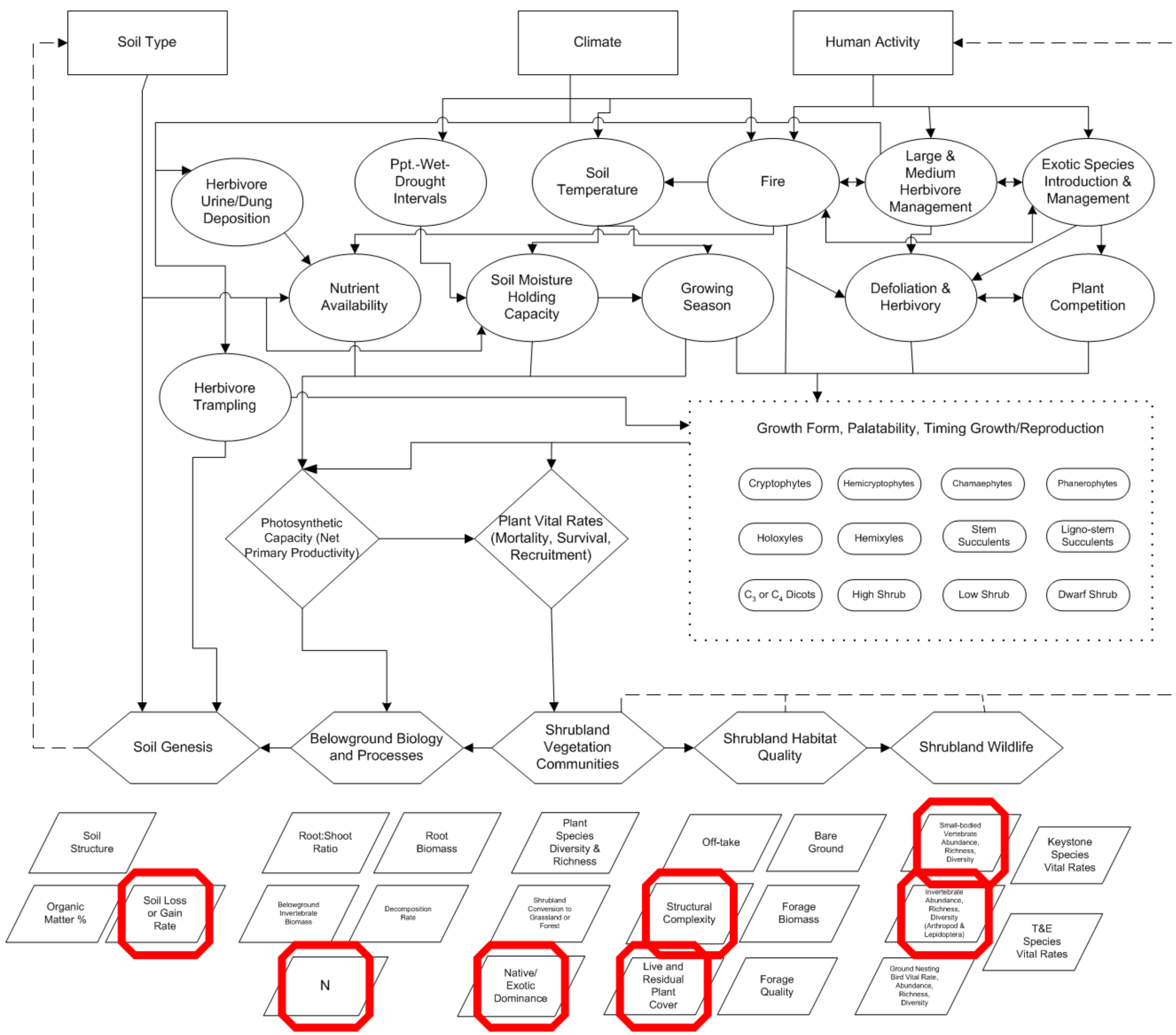
Grassland Submodel-Glenn Plumb

Net Primary Productivity

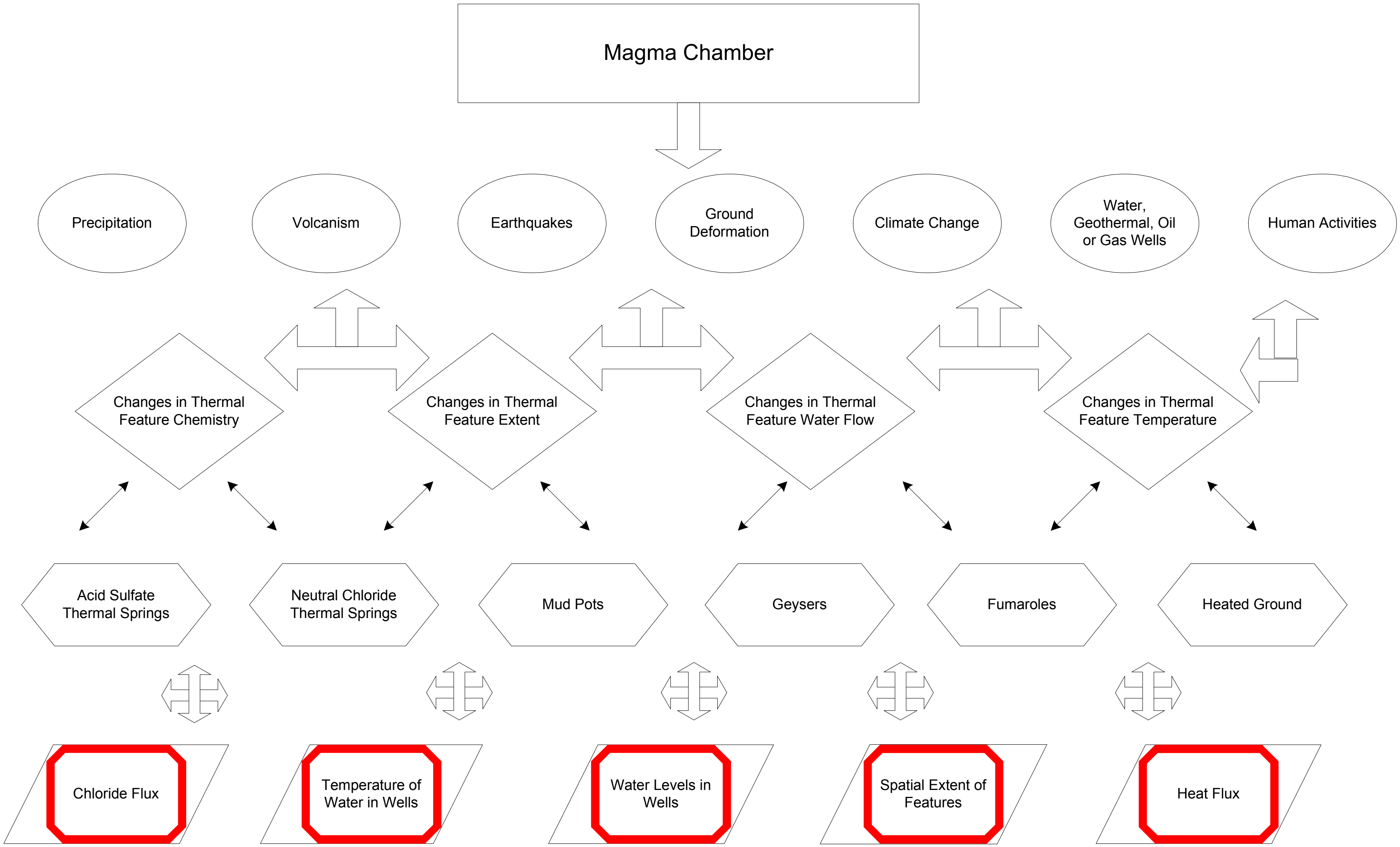


Adapted from *Briggs, et al. 1998. A landscape perspective of patterns and processes. In: Grassland dynamics. Eds. A.K. Knapp, J.M. Briggs, D.C. Hartnett, S.L. Collins. LTER Publications, Oxford University Press, New York.*

Shrubland Model-Glenn Plumb



Geothermal Model-Henry Heasler and Cheryl Jaworowski



APPENDIX E-BREAKOUT GROUP MEMBERS

**Please note: this list reflects those participants who were part of the decision-making process in the resource-area breakout groups.

Air Quality/Climate

Kathy Tonnessen-Moderator	Rocky Mountains-CESU
Ellen Porter	NPS-Air Resources Division
Leora Nanus	USGS
Phil Farnes	Snowcap Hydrology
Cathy Whitlock	University of Oregon

Aquatic/Water Quality

Bob Hall-Moderator	University of Wyoming
Alisa Mast	USGS
Myron Brooks	USGS
Jeff Arnold	Yellowstone National Park
Scott Woods	University of Montana
Sue O'Ney	Grand Teton National Park
Tina Laidlaw	EPA
Alexander Zale	Montana State University
Brian McGlynn	Montana State University

Geotherml/Geology

Duncan Patten-Moderator (morning)	Montana State University
Ann Rodman-Moderator (afternoon)	Yellowstone National Park
Hank Heasler	Yellowstone National Park
Bill Inskeep	Thermal Biology Institute
Kirk Nordstrom	USGS
Ken Pierce	USGS

Terrestrial Vegetation

Dan Tinker-Moderator	University of Wyoming
Duncan Patten-Moderator (afternoon)	
Steve Haynes	Grand Teton National Park
Mary Hektner	Yellowstone National Park
Don Despain	USGS
Jennifer Whipple	Yellowstone National Park
Lisa Rew	Montana State University
Bruce Maxwell	Montana State University
Mary Manning	U.S. Forest Service
Elizabeth Crowe	MT Natural Heritage Program
Roy Renkin	Yellowstone National Park

Terrestrial Vertebrates

Glenn Plumb-Moderator	Yellowstone National Park
Susan Patla	Wyoming Game and Fish

Bob Crabtree	Yellowstone Ecological Research Center
Peter Gogan	USGS
Scott Creel	Montana State University
Chuck Peterson	Idaho State University
Stephen Corn	USGS
Doug Keniath	WY Natural Diversity Database
Susan Wolff	Grand Teton National Park

Invertebrates

Steve Fancy-Moderator	National I&M Coordinator
Diane Debinski	Iowa State University
John Varley	Yellowstone National Park
Michael Ivie	Montana State University

Human Use

Tom Olliff-Moderator	Yellowstone National Park
Dan Burgette	Grand Teton National Park
Laura Gianakos	Bighorn Canyon NRA

APPENDIX F-COMPLETE LIST OF PROPOSED CANDIDATE VITAL SIGNS

**Please note: this list reflects the proposed candidate vital signs given to the participants at the *beginning* of day two. For the ranked list of candidate vital signs, please refer to Appendix I. The code to the right of the proposed candidate vital sign represents its unique ID for database purposes.

All Proposed Candidate Vital Signs

Grouped by Primary and Secondary Resource

Resource		Candidate Vital Sign	
Air Quality			
	Air, Biotic and Abiotic		
		Atmospheric deposition and response in sensitive headwater catchments	AiQu_003
		Atmospheric deposition of nitrogen, sulfur and all major anions and cations	AiQu_006
		Atmospheric deposition of sulfur	AiQu_002
		Change in visibility deciviews	AiQu_005
		Deposition and accumulation of mercury in biota	AiQu_004
		Deposition of trace organics and metals	AiQu_010
		Loading chemical species in snowpacks	AiQu_001
		Loss of forest productivity	AiQu_007
		Nitrogen concentration in streams during spring snowmelt	AiQu_009
		Over-snow vehicles emissions and effects	AiQu_281
		Ozone exposure index--W126	AiQu_008
		Vegetation chemistry	AiQu_207
Aquatic Communities			
	Aquatic Exotic species		
		Exotic fish abundance	AqCo_130
		Exotic fish distribution patterns	AqCo_131
	Aquatic Pathogens/disease		
		Fish pathogens and disease	AqCo_133
	Aquatic Species at risk		
		Cutthroat trout responses to exotic predators	AqCo_276
		Native and exotic community structure, composition, stability	AqCo_127
		Native fish genetic integrity	AqCo_126
		Native fish spawning population vital rates	AqCo_128
Aquatic Habitats			
	Rivers and Streams		
		Channel dimensions	AqHa_123
		In-stream habitat complexity and cover	AqHa_125
		Stream reach geomorphology	AqHa_124
Climate			
	Climate, Biotic and Abiotic		
		Alpine/subalpine climatic conditions and micro-environment	Clim_019
		Basic climatological measurements	Clim_020

Date of "spring green-up"	Clim_018
Date of ice on/off on major lakes	Clim_023
Date of lake overturn	Clim_026
Extent of frozen ground	Clim_024
Extreme Climatological Events	Clim_028
Extreme hydrologic events	Clim_014
Glaciers retreat or increase	Clim_021
Maximum air temperature	Clim_017
Number of cloudy days	Clim_031
Number of rain-on-snow events	Clim_030
Photosynthetically active radiation (PAR)	Clim_029
Plant phenology	Clim_013
Snow cover	Clim_016
Snow-water equivalence of snowpack	Clim_015
Soil climate	Clim_022
Soil temperature	Clim_027
Stream gauging	Clim_012
Surface UV	Clim_025
Total precipitation	Clim_011

Geology and Geothermal

Geothermal Ecosystem

Geothermal plant community composition and exotic species	GeGe_287

Geologic Processes

Earthquake activity	GeGe_051
Volcanic unrest	GeGe_055

Geothermal Microbiology

Contamination of thermal microbial populations	GeGe_056
Geothermal microbial diversity	GeGe_060

Geomorphic Processes

Landslide and debris flows	GeGe_057
Stream channel change	GeGe_290
Stream sediment transport	GeGe_282

Geothermal Processes

Chloride flux in thermal features	GeGe_068
Geothermal feature abundance & distribution	GeGe_054
Geothermal gaseous emissions in the atmosphere over Yellowstone National Park	GeGe_073
Geothermal water chemistry	GeGe_052
Geothermal water flow rate	GeGe_053
Geyser eruption volume and rate	GeGe_059
Heat flow	GeGe_069
Hydro-thermal soil chemistry	GeGe_062
Level and temperature of groundwater associated with thermal features	GeGe_071
Spatial extent of thermal features	GeGe_072
Temperature of ground water associated with thermal features	GeGe_070
Thermal heat transfer	GeGe_058

Soils

Below-ground biomass	GeGe_061

Cryptobiotic crust integrity	GeGe_066
Soil and sediment erosion	GeGe_067
Soil biodiversity	GeGe_065
Soil chemistry	GeGe_063
Soil moisture/temperature/structure	GeGe_293
Soil structure and stability	GeGe_064

Human Activities

Park Visitation

Levels of backcountry day use	HuAc_277
Levels of backcountry overnight use	HuAc_085
Park infrastructure	HuAc_089
Resource consumptive use and hydrologic modification	HuAc_090
Resource violations	HuAc_088
Visitor experience and satisfaction	HuAc_082
Visitor use levels	HuAc_087

Surrounding Environments

Land use and land cover	HuAc_081
Landscape and habitat fragmentation	HuAc_080
Night sky pollution	HuAc_083
Population census by area	HuAc_086
Soundscapes	HuAc_084

Invertebrates - Terrestrial and

Native and Exotic Insects

Critical habitat abundance, distribution and stability	TeIn_074
Exotic insects	TeIn_078
Forest/grassland/shrubland defoliators and consumers	TeIn_250
Insect biomass	TeIn_077
Insect herbivory	TeIn_076
Insect species distribution	TeIn_079
Native insect biodiversity and distribution	TeIn_075
Selected insect species of concern	TeIn_288

Terrestrial Vegetation

Alpine Meadow and Timberline Ecosystems

Alpine plant community characteristics	TeVeg_208
Timberline elevation boundaries	TeVeg_210
Timberline forest density and health	TeVeg_209

Aspen Forest Ecosystems

Aspen community composition and structure	TeVeg_263
Aspen stand extent and distribution in landscape	TeVeg_266
Browsing effects within aspen stands	TeVeg_265

Dry Woodland Ecosystems

Dry woodland community structure and composition	TeVeg_268
Extent and distribution of woodlands	TeVeg_269

Herbaceous Meadow and Grassland

Grassland annual net primary productivity	TeVeg_226
Grassland insect and vertebrate community structure	TeVeg_229
Grassland nitrogen	TeVeg_228
Grassland vegetation annual offtake	TeVeg_227

Grassland vegetation community composition and structure	TeVeg_218
Lodgepole Pine Forest Ecosystem	
Lodgepole pine forest floor litter and coarse woody debris	TeVeg_239
Lodgepole pine plant community composition and exotic species	TeVeg_237
Lodgepole pine snag density	TeVeg_297
Plant species diversity	TeVeg_238
Mixed Conifer Forest Ecosystems	
Age structure of forest	TeVeg_255
Landscape structure and heterogeneity	TeVeg_254
Mixed conifer forest floor litter and coarse woody debris	TeVeg_253
Mixed conifer plant community composition and exotic species	TeVeg_249
Mixed conifer snag density	TeVeg_252
Understory plant species diversity	TeVeg_251
Montane Shrubland Ecosystems	
Shrubland community composition and structure	TeVeg_223
Shrubland exotic species	TeVeg_274
Shrubland growth form diversity	TeVeg_270
Shrubland insect and small vertebrate community structure	TeVeg_271
Shrubland nitrogen	TeVeg_272
Shrubland soil erosion	TeVeg_273
Ponderosa Pine Ecosystems	
Ponderosa pine plant community composition and exotic species	TeVeg_258
Ponderosa pine stand density of live and dead trees	TeVeg_257
Proportion of standing dead trees	TeVeg_259
Soil moisture	TeVeg_256
Riparian and Riverine Wetland Ecosystems	
Browse effects on riparian woody vegetation	TeVeg_225
Exotic plants in riparian zone	TeVeg_211
Riparian condition	TeVeg_212
Riparian vegetation community structure and composition	TeVeg_219
Terrestrial Ecosystems	
Aboveground net primary productivity	TeVeg_241
Area occupied by rare or declining plant community types	TeVeg_236
Bighorn basin plant community composition and exotic species	TeVeg_231
Distribution and trends of exotic plant diseases	TeVeg_233
Exotic terrestrial plant species diversity and/or richness	TeVeg_214
Fire and fuel loading	TeVeg_222
Landscape structure and heterogeneity	TeVeg_240
Lichen distribution, abundance and chemical composition	TeVeg_235
Native terrestrial plant species diversity and/or richness	TeVeg_215
Shrub-steppe community structure and composition	TeVeg_217
Taxonomy and distribution of aquatic vegetation	TeVeg_224
Wet Meadow, Spring, and Depressional	
Wetland extent	TeVeg_291
Wetland plant cover and composition	TeVeg_213
Whitebark Pine Woodland and Forest	
Abundance of replacement tree species	TeVeg_246
Blister rust abundance and spread	TeVeg_248

Burned forest seedbed availability	TeVeg_243
Stand density of high-elevation live and dead whitebark pine trees	TeVeg_245
Whitebark pine cone production	TeVeg_247
Whitebark pine plant community composition and exotic species	TeVeg_286
Whitebark pine snag density	TeVeg_292

Terrestrial Vertebrates

Amphibian and Reptiles

Amphibian and reptile critical food abundance, distribution and stability	TeVer_033
Amphibian habitat quality, abundance, distribution and population vital rates	TeVer_032

Birds

Clark's Nutcracker abundance	TeVer_242
Colony nesting bird population abundance, distribution, vital rates and productivity	TeVer_037
Neotropical bird population abundance, distribution and vital rates	TeVer_035
Raptor population abundance, distribution and productivity	TeVer_038
Riparian wildlife species	TeVer_260
Selected sensitive bird species abundance, distribution and productivity	TeVer_034
Song bird population abundance and distribution	TeVer_036

Mammals

Bat occurrence, distribution and abundance	TeVer_045
Beaver presence and population estimates	TeVer_261
Bighorn sheep vital rates	TeVer_267
Human-carnivore interactions	TeVer_044
Large carnivore population abundance and distribution	TeVer_039
Low-elevation foraging by grizzly bears in autumn	TeVer_244
Meso-carnivore population abundance and distribution	TeVer_285
Native ungulate behavior and migration dynamics	TeVer_042
Predator-prey dynamics	TeVer_041
Rodents and insectivores (<250g) population, abundance and distribution	TeVer_283
Rodents and Lagomorphs (>250g) population, abundance and distribution	TeVer_284
Small-mammal population abundance, distribution and vital rates	TeVer_043
Ungulate population abundance, distribution and productivity	TeVer_040

Terrestrial Vertebrates

Amphibian occurrence	TeVer_279
Associated animal populations	TeVer_264
Emerging pathogens on vertebrate species	TeVer_050
Invasive vertebrate species richness and distribution	TeVer_048
Native species richness	TeVer_047
Pattern of non-park land-use changes	TeVer_289
Reptile occurrence	TeVer_278
Vertebrate diseases	TeVer_049
Wetland associated wildlife species	TeVer_262
Wildlife habitat loss and degradation	TeVer_046

Water Quality

Ground Water

Ground water chemistry	WaQu_299
Ground water hydrology	WaQu_300
Groundwater level and aquifer volume	WaQu_195

Lakes and Reservoirs

Algal species composition and biomass	WaQu_275
Alkalinity	WaQu_105
Bed sediment chemistry (adsorbed)	WaQu_119
Chlorophyll a	WaQu_101
Continuous water temperature	WaQu_295
Core parameters	WaQu_094
Dissolved organic carbon	WaQu_106
E. coli	WaQu_097
Major ion chemistry	WaQu_091
Metals	WaQu_098
Phosphorus concentrations in aquatic ecosystems	WaQu_093
Phytoplankton community structure	WaQu_103
Reservoir elevation	WaQu_121
Secchi transparency	WaQu_099
Zooplankton community structure	WaQu_104

Rivers and Streams

Alkalinity	WaQu_118
Bed sediment chemistry (adsorbed)	WaQu_298
Chlorophyll a	WaQu_116
Continuous water temperature	WaQu_096
Core parameters	WaQu_112
E. coli	WaQu_113
Major ion chemistry	WaQu_107
Metals	WaQu_114
Nitrogen concentrations in aquatic ecosystems	WaQu_110
Periphyton community structure, chlorophyll a	WaQu_117
Phosphorus concentrations in aquatic ecosystems	WaQu_111
River invertebrate assemblages	WaQu_109
Streamflow	WaQu_120
Total suspended solids	WaQu_115

Watershed

Watersheds

Watershed budgets	Wate_301

<u>APPENDIX G-SELECTION CRITERIA EXPLANATIONS AND APPENDICES</u>

ECOLOGICAL RELEVANCE

Criterion #1 - <u>The candidate vital sign has high ecological importance with a demonstrated linkage between the vital sign and the ecological structure or function that it is supposed to represent, based on a conceptual model and/or supporting ecological literature.</u>

Often, the selection of a relevant indicator is obvious from the assessment question and from professional judgement. However, a conceptual model can be helpful to demonstrate and ensure an indicator's ecological relevance, particularly if the indicator measurement is a surrogate for measurement of the valued resource. It must be demonstrated that the proposed indicator is conceptually linked to the ecological function of concern. A straightforward link may require only a brief explanation. If the link is indirect or if the indicator itself is particularly complex, ecological relevance should be clarified with a description, or conceptual model. *(*Adapted from *Jackson, L.E., J.C. Kurt and W.S. Fisher, eds. 2000. Evaluation guidelines for ecological indicators. EPA/620/R-99/05. U.S. E.P.A, Office of Research and Development, Research Triangle Park, NC. 107pp.)*

Criterion #2 - *<u>The candidate vital sign provides relevant information that is applicable to multiple scales of ecological organization.</u>*

The term "multiple scales of ecological organization" refers to the hierarchical ecological structure including individuals, populations, communities, landscapes and ecosystems. Accordingly, information from one scale can sometimes provide insight relevant to other scales, thus increasing the applicability of the candidate vital sign if the information gathered from monitoring it can be useful at multiple scales of ecological organization. *(*Adapted from *Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10.)*

<u>RESPONSE VARIABILITY</u>

Criterion #3 - The candidate vital sign responds to ecosystem stressors in a predictable manner with known statistical power.

Predictable manner refers to the lack of ambiguity in the response of the candidate vital sign to ecosystem stressors. The response should be clear and predictable even given gradual change in the stressor. In a best-case scenario, the candidate vital sign's response is observable before the system is actually threatened. *(Adapted from Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10.)* **Statistical power** refers to the ability of a candidate vital sign to have a low chance of Type I and II errors. If a change has occurred in an ecosystem, a vital sign will either detect the change or detect no change. If the vital sign detects a change when a real change has occurred, then no error has occurred. However, if the vital sign detects a change when no real change has occurred, then a false-positive, or Type I, error has been made. Making a false positive error is costly, monetarily speaking, because usually unnecessary action ensues. If change has occurred and the vital sign does not detect this change, then a missed-change, or Type II, error has occurred. Therefore, although action should be taken, most likely the change will go unnoticed. *(*Adapted from *Booth, G.D. Monitoring data and the risks of management decisions. USDA Forest Service publication.)*

	No change has taken place	**There has been a real change**
Vital sign detects change	False-positive Error (Type I)	No Error
Vital sign detects no change	No Error	Missed-change Error (Type II)

Criterion #4 - *<u>The candidate vital sign is anticipatory and sensitive enough to stressors to provide an early warning of change.</u>*

In this case, **sensitivity** does not necessarily refer to a candidate vital sign that is responsive to any and all dramatic changes in the system; but, rather, those that react to subtle stressors in the system, giving early warning of potentially reduced system integrity. (Adapted from *Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10.*)

Criterion #5 - *<u>The candidate vital sign has low natural variability and has high signal-to-noise ratio.</u>*

Signal-to-noise ratio refers to the measure of how the signal from the candidate vital sign compares with background noise. Noise is defined as the uncommon variance of the data. The strength of the signal is positively correlated with the quality of the candidate vital sign as an indicator of ecosystem health. Therefore, the higher the signal-to-noise ratio, the better the candidate vital sign is at predicting ecosystem changes. If the signal and noise are of equal strength, the signal borders on unreadable because the noise strongly competes with it. (Adapted from *Cook, E.R. and L.A. Kairiukstis. Methods of dendrochronology: applications in the environmental sciences. 1990. Dordrecht, The Netherlands.*)

MANAGEMENT RELEVANCE

Criterion #6 - The candidate vital sign is stated in specific park management goals, GPRA goals or Business Plan Standards.

Park Management Goals - The overall natural resource management goal of the National Park Service is as follows: *The National Park Service will preserve the natural resources, processes, systems and values of units of the national park system in an unimpaired condition, to perpetuate their inherent integrity and to provide present and future generations with the opportunity to enjoy them.* (Adapted from *Management Policies 2001. National Park Service publication.*)

The key management-related provision stated in the National Park Service Organic Act of 1916 is: *[The National Park Service] shall promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified...by such means and measures as conform to the fundamental purpose of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.* (Adapted from *Management Policies 2001. National Park Service publication.*) **Please refer to specific park management goals for Grand Teton and Bighorn Canyon in Appendix A.

GPRA Goals - The **Government Performance and Results Act (GPRA) goals** can be divided into four focal areas: 1) preserve park resources, 2) provide for the public enjoyment and visitor experience of parks, 3) strengthen and preserve natural and cultural resources and enhance recreational opportunities managed by partners and 4) ensure organizational effectiveness. (Adapted from *Yellowstone National Park Business Plan Fiscal Year 2002*.) **Please refer to specific GPRA goals in the appendix.

Business Plan Standards - *According to Yellowstone National Park's Business Plan (Fiscal Year 2002), resource protection encompasses all activities related to the management, preservation and protection of the park's cultural and natural resources. Activities include research, restoration efforts, species-specific management programs, wildland fire management, archives and collections management, and historic site protection and information integration activities. (Adapted from* Yellowstone National Park Business Plan Fiscal Year 2002.*) **Please refer to specific business plan standards for Yellowstone National Park in Appendix A.*

Criterion #7 - <u>There is a demonstrated, direct application of candidate vital sign measurement data to current key management decisions, or for evaluating past management decisions.</u>

Ultimately, an indicator is useful only if it can provide information to support a management decision or to quantify the success of past decisions. Policy makers and resource managers must be able to recognize the implications of indicator results for stewardship, regulation, or research. An indicator with practical application should display one or more of the following characteristics: responsiveness to a specific stressor, linkage to policy indicators, utility in cost-benefit assessments, limitations and boundaries of application, and public understanding and acceptance. Detailed consideration of an indicator's management utility may lead to a re-examination of its conceptual relevance and to a refinement of the original assessment question. (Adapted from *Jackson, L.E., J.C. Kurt and W.S. Fisher, eds. 2000. Evaluation guidelines for ecological indicators. EPA/620/R-99/05. U.S. E.P.A, Office of Research and Development, Research Triangle Park, NC. 107pp. and Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10.) **Please refer to the <u>Threats and Management Issues</u> table in Appendix A.*

FEASIBILITY OF IMPLEMENTATION

Criterion #8 - <u>The candidate vital sign's cost of measurement is not prohibitive.</u>

Cost is often the limiting factor in considering to implement an indicator. Estimates of all implementation costs should be evaluated. Cost evaluation should incorporate economy of scale, since cost per indicator or cost per sample may be considerably reduced when data are collected for multiple indicators at a given site. Costs of a pilot study or any other indicator development needs should be included if appropriate. The vital sign not only has to be relevant to monitoring but implementation also has to be feasible, practical and affordable. Sampling methods may include simple, low-tech or low-cost data collection methods, or more complex or expensive collection methods may be cost-effective, e.g. data collection every five years results in low annual costs. Consideration should be given to data collection methods, logistical requirements, data processing and information management, data quality, and costs in terms of time, money and personnel (Adapted from *Jackson, L.E., J.C. Kurt and W.S. Fisher, eds. 2000. Evaluation guidelines for ecological indicators. EPA/620/R-99/05. U.S. E.P.A, Office of Research and Development, Research Triangle Park, NC. 107pp.*).

Criterion #9 - *<u>Impacts of the candidate vital sign's measurement meet NPS standards.</u>*

Sampling activities for indicator measurements should not significantly disturb a site. Evidence should be provided to ensure that measurements made during a single visit do not affect the same measurement at subsequent visits or, in the case of integrated sampling regimes, simultaneous measurements at the site. Also, sampling should not create an adverse impact on protected species, species of special concern, or protected habitats. Any impact due to data collection of a specific park resource on that resource or on the surrounding environment can be considered impairment of a National Park Service natural resource or value if it impacts a resource or value whose conservation is:

- Necessary to fulfill specific purposes identified in the enabling legislation or proclamation of the park
- Key to the natural or cultural integrity of the park or to opportunities for enjoyment of the park
- Identified as a goal in the park's general management plan or other relevant NPS planning documents.

However, an impact is less likely to be considered impairment if it is the unavoidable result of an action necessary to restore or conserve the integrity of a park natural resource or value. All proposals for natural resource use and measurement within a National Park are evaluated against the following four points:

- Consistency with applicable laws, Executive Orders, regulations and policies
- Consistency with existing plans for public use and resource management
- Actual and potential effects on park resources and values
- Total costs to the Service, and whether the public interest will be served.

(Adapted from *Yellowstone National Park Business Plan Fiscal Year 2002*.) **Please refer to specific NPS standards in Appendix B.

Criterion #10 - *<u>The candidate vital sign is relatively easy to measure and has measurable results that are repeatable with different personnel.</u>*

A vital sign should be straightforward with methodology that is relatively easy to understand, and simple to apply. Measurement of the vital sign should not be dependent on a single expert, but rather should incorporate expert systems that can be implemented by adequately trained field staff. The logistical requirements should warrant practical implementation and the length of time required to collect, analyze and report the data of a vital sign should not be prohibitive. *(*Adapted from *Jackson, L.E., J.C. Kurt and W.S. Fisher, eds. 2000. Evaluation guidelines for ecological indicators. EPA/620/R-99/05. U.S. E.P.A, Office of Research and Development, Research Triangle Park, NC. 107pp. and Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10.)*

INTERPRETATION AND UTILITY

Criterion #11 - *The candidate vital sign's response can be distinguished between natural variation and anthropogenic impact-induced variation.*

The vital sign should have a well-documented reaction to both natural disturbances and anthropogenic stresses in the system. This criterion would then apply to metrics that have been extensively studied and have well-developed models and clearly established patterns of response. (Adapted from *Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10 and Angermeier, P.L. 1997. Conceptual roles of biological integrity and diversity. Pp: 49-65. In: Williams, J.E., C.A. Wood, and M.P. Dombeck, eds. Watershed Restoration Principles and Practicies, American Fisheries Society, Bethesda, MD. 559 pp.)*

Criterion #12 - *The candidate vital sign is helpful in identifying the causal mechanism of an ecological response.*

Although overlooked in the emerging literature on ecological vital signs (also indicators), the ability for one or more integrative vital signs to provide insight into the causal mechanisms of an observed ecosystem response will be crucial to NPS needs. In order for vital sign information to be translated into management responses, park managers will need to be able to utilize the vital sign information to assess what processes are causing the measured ecosystem response and then translate this understanding into deliberate management decisions to intervene and attempt mitigation or accept that the observed departure from the range of natural variability cannot be mitigated. (Adapted from *Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. Wiley, NY and Angermeier, P.L. 1997. Conceptual roles of biological integrity and diversity. Pp: 49-65. In: Williams, J.E., C.A. Wood, and M.P. Dombeck, eds. Watershed Restoration Principles and Practices, American Fisheries Society, Bethesda, MD. 559 pp.)*

Criterion #13 - *Historic databases and baseline conditions for the candidate vital sign are already known.*

Threshold values or ranges of values are often established to facilitate the ability to interpret whether vital sign information suggests an important departure from the range of natural variability. This is because there can be important natural spatial and temporal variation in measurable ecosystem responses with and across years. The ability for a vital sign to permit discrimination of natural variability along known condition gradient(s) from unacceptable ecological conditions will need to be based upon documented baseline conditions, known thresholds, historical records or observed responses at reference sites along an important condition gradient. (Adapted from *Environment Canada. 2000. Selecting core variables for tracking ecosystem change at EMAN sites. Final Report to Environment Canada. Geomatics International, Inc., Guelph, Ontario. http:/www.eman-rese.ca and Angermeier, P.L. 1997. Conceptual roles of biological integrity and diversity. Pp: 49-65. In: Williams, J.E., C.A. Wood, and M.P.*

Dombeck, eds. Watershed Restoration Principles and Practices, American Fisheries Society, Bethesda, MD. 559 pp.)

APPENDIX A

**This information appends the expanded selection criteria information.

MANAGEMENT RELEVANCE

Park Management Goals

Specific park management goals are taken from each park's General Management Plan or Master Plan. The specific management goals of Bighorn Canyon National Recreation Area, according to its General Management Plan, are:

> *The preservation of the natural environment for the enjoyment of the recreation area visitors and for the integrity of the ecosystems...*

According to the Master Plan of Grand Teton National Park states the following purpose:

> *To protect the scenic and geological values of the Teton Range and Jackson Hole, and to perpetuate the Park's indigenous plant and animal life. The Park will interpret these natural and scenic values, in association with the historical significance of the region, in a manner that preserves these resources for the benefit and d pleasure of present and future generations.* (Adapted from *Greater Yellowstone Network Phase I Report.*)

GPRA Goals

Each of the four GPRA goal focal areas can be separated into specific mission goals, as follows:

Preserve park resources: 1) natural and cultural resources and associated values are protected, restored and maintained in good condition and managed within their broader ecosystem and cultural context; and 2) the National Park Service contributes to knowledge about natural and cultural resources and associated valued; management decisions about resources and visitors are based on adequate scholarly and scientific information.

Provide for the public enjoyment and visitor experience of parks: 1) visitors safely enjoy and are satisfied with the availability, accessibility, diversity and quality of park facilities, services and appropriate recreational opportunities; and 2) park visitors and the general public understand and appreciate the preservation of parks and their resources for this and future generations.

Strengthen and preserve natural and cultural resources and enhance recreational opportunities managed by partners: 1) natural and cultural resources are conserved through formal partnership programs; 2) through partnerships with other federal, state and local agencies and non-profit organizations, a nationwide system of parks, open space, rivers and trails provides educational, recreational and conservation benefits for the American people; and 3) assisted through federal funds and programs, the protection of recreational opportunities is achieved through formal mechanisms to ensure continued access for public recreational use.

<u>Ensure organizational effectiveness</u>: 1) the National Park Service uses current management practices, systems and technologies to accomplish its mission; and 2) the National Park Service increases its managerial resources through initiatives and support from other agencies, organizations and individuals. (Adapted from *Yellowstone National Park Business Plan Fiscal Year 2002*.)

Specific GPRA goals for the Network parks are included in the table below.

NPS GPRA GOALS	**Bighorn Canyon National Recreation Area**	Exotic Vegetation Species: by September 30, 2005, exotic vegetation on 70.25 (2.81%) acres of an estimated 2,500 targeted acres of Bighorn Canyon lands, as of FY 1999, is contained.
		Water Quality: by September 30, 2005, Bighorn Canyon has unimpaired water quality.
		Natural/Cultural Resource Inventories: by September 30, 2005, 4 (66.6%) of 6 Bighorn Canyon primary natural/cultural resource inventories are completed.
		Vital Signs: by September 30, 2005, Bighorn Canyon has identified its vital signs for natural resource monitoring.
	Yellowstone National Park	Natural Resources Fauna: by September 30, 2005, 356 (95%) of the 375 self-sustaining and free-ranging wildlife, native fish and birds identified in Yellowstone National Park as of 1999 are preserved and maintained.
		Geothermal Features: By September 30, 2005, 90 (90%) of the 100 indicator geothermal features identified in Yellowstone National Park as of 1999 are in good condition.
		Native Species of Special Concern: by September 30, 2005, four of Yellowstone National Park's native species of special concern (trumpeter swan, white pelican, pronghorn antelope and Yellowstone sand verbena), as of 1999, have an improved or stable status.
		Exotic Plant Species: by September 30, 2005, invasive exotic vegetation species on 20-22 (2.6%) of 822 targeted acres of Yellowstone National Park lands, as of FY 1999, are eradicated or contained.
		T&E Species Improved: by September 30, 2005, one (the gray wolf) (33%) of Yellowstone National Park's three identified populations of federally listed threatened and endangered species with critical habitat on park lands and/or requiring NPS recovery actions, as of 1999, has an improved status.
		T&E Species Stable: by September 30, 2005, two (the grizzly bear and bald eagle) (66%) of Yellowstone National Park's three identified populations of federally listed threatened and endangered species with critical habitat on park lands and/or requiring NPS recovery actions, as of 1999, have a stable status.
		Air Quality: by September 30, 2005, air quality in Yellowstone National Park has remained stable or improved relative to FY 1998 conditions.
		Water Quality: by September 30, 2005, Yellowstone National Park has unimpaired water quality.
		Vital Signs: by September 30, 2005, Yellowstone National Park has identified its vital signs for natural resource monitoring.
	Grand Teton National Park	Exotic Plant Species: by September 30, 2005, spotted knapweed and other alien vegetation species are contained on 20,000 (100%) of 20,000 acres targeted in Grand Teton National Park and the John D. Rockefeller Jr. Memorial Parkway.
		T&E Species: by September 30, 2005, 2 of the 4 federally listed threatened and endangered species NOT having critical habitat in Grand Teton and the Parkway and NOT requiring NPS recovery actions, as of 1997, have an improved status. Monitoring continues on the remaining 2 federally listed species.

		Native Species of Species Concern: by September 30, 2005, 1 of 2 (50%) of Grand Teton National Park and Parkway populations of plant and/or animal species of special concern (e.g. state-listed threatened and endangered species, endemic or indicator species, or native species classified as pests) are at scientifically acceptable levels.
		Air Quality: by September 30, 2005, air quality in Grand Teton National Park has remained stable or improved relative to FY 1998 conditions.
		Water Quality: by September 30, 2005, Grand Teton National Park and Parkway continue to have unimpaired water quality.
		Wildlife Research and Monitoring: by September 30, 2005, 9 of 9 (100%) of Grand Teton National Park and Parkway species of concern will continue to be monitored to provide sufficient information to assist in management decisions.
		Resource Inventories: by September 30, 2005, 50% of the available natural resource data sets for Grand Teton National Park will be collected and evaluated.
		Vital Signs: by September 30, 2005, Grand Teton National Park has identified its vital signs for natural resource monitoring.

(Table adapted from *Strategic Plan for Grand Teton National Park and John D. Rockefeller Jr. Memorial Parkway October 1, 2001- September 30, 2005. Strategic Plans. 2001.* <http://im.den.nps.gov/Documents/GpraPlans/GRTE%2Edoc> *(3 Apr. 2003); The Strategic Plan for Yellowstone National Park 2001-2005. Strategic Plans. 2000.* <http://im.den.nps.gov/Documents/GpraPlans/YELL%2Epdf> *(3 Apr. 2003)*; *The Strategic Plan for Bighorn Canyon National Recreation Area 2001-2005. Strategic Plans. 2001.* <http://im.den.nps.gov/Documents/GpraPlans/BICA%2Epdf> *(3 Apr. 2003)*)

Business Plan Standards

The following aspects of Yellowstone's natural resources are included in the Natural Resource Protection section of Yellowstone National Park's Business Plan:

- Air, Soils and Geology-including the monitoring of geothermal features, weather, air quality, river gauging stations and volcanic and earthquake unrest
- Backcountry and Wilderness Management-including 300 remote sites and 1,000 miles of trails
- Bear Management-including the reduction of bear-human conflicts and the monitoring of bear populations and ecology
- Bison Management-including the Interagency Bison Management Plan (a brucellosis transmission risk management strategy relying on strategic hazing and capture and removal techniques) and vaccination of bison calves and yearlings
- Elk and Other Ungulate Management-including monitoring of elk, pronghorn antelope, bighorn sheep, mountain goats, moose and whitetail and mule deer populations and ecology
- Fisheries and Aquatic Resources-including the control of invasive exotic species (e.g. lake trout, whirling disease, New Zealand mud snails) and the management of consumptive use through fishing permits and regulations
- Natural Resource Protection-including the protection of resources from human-caused threats and the protection of humans from wildlife, geothermal and other natural threats

- Natural Resource Research, Publications and Events-including the creation of a resource management-based research program that will benefit residential education programs and produce publications for various audiences
- Other Wildlife Management-including the management of birds, reptiles, amphibians, invertebrates, small mammals and mid-sized carnivores (e.g. Canada lynx, cougars, wolverines) and the Integrated Pest Management program
- Vegetation Management-including wetlands mapping and preservation, invasive exotic species control, rare vascular plant documentation, hazard tree removal and vegetation ecology studies
- Wildland Fire-including the encouragement of natural fires except when they threaten irreplaceable historic structures and sharing fire management resources with surrounding National Forest land
- Wolf Management-including monitoring wolves and their impacts on the ecosystem

Additionally, included in the Yellowstone Business Plan is the vision of the park, which encompasses the following areas:

- Public enjoyment and visitor experience
- Resource preservation
- Efficiency and effectiveness
- Safety

(Adapted from *Yellowstone National Park Business Plan Fiscal Year 2002*.)

APPENDIX B

Feasibility of Implementation

National Park Service Standards

For example, the following uses of National Park Service land are restricted and require special prior approval:

- Off-road vehicle use (Executive Order 11644)
- Aircraft over flights (Director's Order 47)
- Telecommunication antenna sites (Director's Order 53)
- Consumptive uses (i.e. collecting natural products) are only allowed when they are:
    - Specifically authorized by federal law or treaty rights
    - Specifically authorized pursuant to other existing rights
    - Some pre-specified grazing activities
    - Traditional visitor activities that are authorized in accordance with NPS general regulations.

(Adapted from *Management Policies 2001. National Park Service publication.*)

These additional conditions are placed on research permits obtained for Yellowstone National Park:

- All equipment left in the field including plot markers must be specifically authorized in advance. If you are authorized to place plot markers in Yellowstone, they must be eight-penny nails with an optional washer
- All VHF and GPS collars on wildlife must be camouflaged to blend in with the animal. The antennas on the collars must also be as invisible as possible. All collars must be removed at the completion of the study by either blow-off capabilities or cotton (rot-away) spacers
- Specific authorization must be obtained in advance before using chemicals or hazardous materials
- A research permit does not authorize you to enter closed or restricted areas in Yellowstone. Examples of restricted areas include most service roads, bear management areas, some thermal areas, some bird nesting areas, and wolf den sites, and trout spawning areas
- Cultural resources must not be adversely impacted by your research activities. Any ground disturbances must be specifically authorized in advance
- If your research requires flying in the park, you must request authorization in advance. You must also comply with FAA and Yellowstone National Park flight regulations
- The Permittee agrees to notify the Superintendent of Yellowstone National Park of every subject discovery or invention that relates in any respect to research results derived from use of any research specimens or other materials collected from Yellowstone National Park, or that may be patentable or otherwise protected under the intellectual property (IP) laws of the United States or other jurisdiction

- Travel within the park is restricted to only those methods that are available to the general public unless otherwise specified in additional stipulations associated with this permit.

(Adapted from *Yellowstone National Park Permit Conditions 2003.*)

The following conditions apply to specimen collection in Yellowstone National Park:

- Collection of archeological materials without a valid Federal Archeology Permit is prohibited.
- Collection of federally listed threatened or endangered species without a valid U.S. Fish and Wildlife Service endangered species permit is prohibited.
- Collection methods shall not attract undue attention or cause unapproved damage, depletion, or disturbance to the environment and other park resources, such as historic sites.
- New specimens must be reported to the NPS annually or more frequently if required by the park issuing the permit. Minimum information for annual reporting includes specimen classification, number of specimens collected, location collected, specimen status (e.g., herbarium sheet, preserved in alcohol/formalin, tanned and mounted, dried and boxed, etc.), and current location.
- Collected specimens that are not consumed in analysis or discarded after scientific analysis remain federal property. The NPS reserves the right to designate the repositories of all specimens removed from the park and to approve or restrict reassignment of specimens from one repository to another. Because specimens are Federal property, they shall not be destroyed or discarded without prior NPS authorization.
- Each specimen (or groups of specimens labeled as a group) that is retained permanently must bear NPS labels and must be accessioned and cataloged in the NPS National Catalog. Unless exempted by additional park-specific stipulations, the permittee will complete the labels and catalog records and will provide accession information. It is the permittee's responsibility to contact the park for cataloging instructions and specimen labels as well as instructions on repository designation for the specimens.
- Collected specimens may be used for scientific or educational purposes only, and shall be dedicated to public benefit and be accessible to the public in accordance with NPS policies and procedures.
- Any specimens collected under this permit, any components of any specimens (including but not limited to natural organisms, enzymes or other bioactive molecules, genetic materials, or seeds), and research results derived from collected specimens are to be used for scientific or educational purposes only, and may not be used for commercial or other revenue-generating purposes unless the permittee has entered into a Cooperative Research And Development Agreement (CRADA) or other approved benefit-sharing agreement with the NPS. The sale of collected research specimens or other unauthorized transfers to third parties is prohibited. Furthermore, if the permittee sells or otherwise transfers collected specimens, any components thereof, or any products or research results developed from such specimens or their components without a CRADA or other approved benefit-sharing agreement with NPS, permittee will pay the NPS a royalty rate of twenty percent (20%) of gross revenue from such sales or other revenues. In addition to such royalty, the NPS may seek other damages to which the NPS may be entitled including but not limited to injunctive relief against the permittee.

(Adapted from *General Conditions for Scientific Research and Collection Permit. Department of the Interior.*)

APPENDIX H-CANDIDATE VITAL SIGNS SCORING COMMENTS

**Please note: not all candidate vital signs are represented in the following table. Only those candidate vital signs that had recorded comments from day two of the workshop are found in this table.

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Deposition and accumulation of mercury in biota	GRYN	Air, Biotic and Abiotic	(q1)-n/a; mercury is an important toxic air contaminant that affects human health; needs further study to assess ecological impact and addresses linkages between deposition and accumulation in biota	(q2,3,4)-not enough information on this important vital sign to assess variability			(q11)-this is an important issue (q13)-some information from ice and sediment cores
Change in visibility deciviews	GRYN	Air, Biotic and Abiotic	We are mandated to do this. Already underway in YELL, need to do GRTE and BICA because it is difficult to extract information from YELL to other parks.				
Atmospheric deposition of nitrogen, sulfur and all major anions and cations	GRYN	Air, Biotic and Abiotic	This is a stressor variable; needed in all parks; comprehensive, continuous coverage is essential.				
Over-snow vehicles emissions and effects	GRTE	Air, Biotic and Abiotic		(q3) N/A variable is a stressor (q4) N/A (q5) N/A			

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Fish pathogens and disease	GRYN	Aquatic Pathogens/disease					(q12) whirling disease is an exception
Stream reach geomorphology	GRYN	Rivers and Streams		(q3)-only change is predictable, not the direction of change			
Stream gauging	GRYN	Climate, Biotic and Abiotic	(q1)-comprehensive coverage of stream gauging in all parks and networks; need cooperation of USGS	(q3)-variable is critical stressor and response variable; needs to be long-term continuous monitoring.			
Snow cover	GRYN	Climate, Biotic and Abiotic	(q1)-easy to measure with remote sensing				
Date of "spring green-up"	GRYN	Climate, Biotic and Abiotic	One opinion in group is that we can estimate this parameter with weather data. We want to correlate weather data with spring green-up. Spring green-up is a remotely sensed variable. Need comprehensive coverage.	This is one of many variables that could be remotely sensed. Needs to be long-term continuous monitoring.			

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Basic climatological measurements	GRYN	Climate, Biotic and Abiotic	We feel that these measurements are critical to all parks and should have comprehensive coverage of all ecosystems. All measurements should be coordinated with NWS and NRCS and across NPS. Should be coordinated across all NPS networks and parks.	This is stressor variable, not response variable, so we've answered 'yes' to all. Needs to be long-term continuous monitoring.			
Date of ice on/off on major lakes	GRYN	Climate, Biotic and Abiotic	Observational data=should be used to verify remotely sensed information				
Extreme Climatological Events	GRYN	Climate, Biotic and Abiotic	Snow crusting can also be important; extreme events are important variables to measure for climate change; important human safety variables	(q3)-not appropriate for variable			
Geyser eruption volume and rate	YELL	Geothermal Processes		(q4)-with some		(q8)-may make sense in some places; volume is a problem	(q13)-'yes' not for volume

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Chloride flux in thermal features	YELL	Geothermal Processes	(q1)-measurement of heat flux to surface	(q3)-disagreement on stressor		(q8)-technique relies upon river gauging stations	
Level and temperature of groundwater associated with thermal features	YELL	Geothermal Processes	activity of geothermal systems			(q8)-assumes use at existing wells (q9)-assumes use at existing wells	
Geothermal gaseous emissions in the atmosphere over Yellowstone National Park	YELL	Geothermal Processes	part of geothermal system				(q13)-spotty
Stream sediment transport	GRYN	Geomorphic Processes	(q1)-landscape stability	(q5)-over many years of measurements	(q6)-required by NAQWA	(q8)-suspended sediment easier to measure than bedload	(q13)-yes in some areas; no in others
Landscape and habitat fragmentation	GRYN	Surrounding Environment s		(q3) vital sign is a stressor	(q6) In park-driven by mgmt plans, outside-driven by counties, therefore, varies by county.	(q8,q10) Remotely sensed data can be used to classify land use and fragmentation. Cover is more difficult and costly.	

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Levels of backcountry overnight use	GRTE	Park Visitation	(q1) Concern about on-site impacts and impacts that migrate off-site. (q2) Concern about pristine areas that will become less pristine through use - this is not ecologically important until you get off-site impacts	(q3)This vital sign is an ecosystem stressor. (q4)Based on Cole and others, this vital sign is predictable.		(q8) Measuring levels of use is very cheap. Measuring impact of use is more costly, but not prohibitive.	
Levels of backcountry overnight use	YELL	Park Visitation	(q1) Concern about on-site impacts and impacts that migrate off-site. (q2) Concern about pristine areas that will become less pristine through use - this is not ecologically important until you get off-site impacts	(q3)This vital sign is an ecosystem stressor. (q4)Based on Cole and others, this vital sign is predictable.		(q8) Measuring levels of use is very cheap. Measuring impact of use is more costly, but not prohibitive.	
Visitor use levels	GRYN	Park Visitation	(q1)Visitor use and associated infrastructure is the biggest ecological impact in parks.	(q3)vital sign is a stressor.		(q8)Visitor use levels are easy to measure, impacts are difficult. visitor use levels are easy to measure, impacts are difficult.	

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Resource violations	GRYN	Park Visitation	(q1) Yes for BICA (cattle trailing) No for YELL, GRTE. (q2) Yes for BICA with cattle trailing.	(q1) vital sign is a stressor			
Park infrastructure	GRYN	Park Visitation	(q1) This vital sign is a stressor	(q3) Depends on species, individual, habitat type. (q4) Anticipating in that one can predict roads will bring exotics and increased roadkill. (q5) Some things (roadkill) are well known, some are not known at all.		(q8) But depends on which metric one chooses (q10) Again, depends on metric	(q12) depends on metric (q13) yes- vegetation, roadkill, etc.
Resource consumptive use and hydrologic modification	GRYN	Park Visitation	(q1) Hunting has possible ecological impact to muledeer and raccoons (BICA) and small mammals	(q3) vital sign is an ecosystem stressor			

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Levels of backcountry day use	GRTE	Park Visitation	(q1) Some impacts, but this is more of a social impact issue	(q3)vital sign is a stressor.		(q8) Cost of monitoring this sign can be very high (e.g.. GRTE has a proposal to monitor day use for around 150,000) but it is not prohibitive.	(q11) This VS is a social issue primarily. (q12) YELL has numbers of day users measured in 1992-93, GRTE has numbers from 1986-87.
Levels of backcountry day use	YELL	Park Visitation	(q1) Some impacts, but this is more of a social impact issue than a (unfinished	(q3)vital sign is a stressor.		(q8) Cost of monitoring this sign can be very high (e.g.. GRTE has a proposal to monitor day use for around 150,000) but it is not prohibitive.	(q11) This VS is a social issue primarily. (q12) YELL has numbers of day users measured in 1992-93, GRTE has numbers from 1986-87.
Native insect biodiversity and distribution	GRYN	Native and Exotic Insects			(q6) need to check	(q8) quite in expensive per species, but more costly by indicator (q10) collection easy, but identification is difficult and expensive	(q13) some data available, but not adequate

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Exotic insects	GRYN	Native and Exotic Insects		(q3) Presence of insects are an ecosystem stressor		(q8) high cost for one species, but low considering number of species involved.	(q13) Some species
Forest/grasslan d/shrubland defoliators and consumers	GRYN	Native and Exotic Insects	(q1) combined 3 previous vital signs: Beetle and budworm pop., Insect herbivory and Insect biomass				(q13) Yes for forest-related species but not for grasshoppers
Selected insect species of concern	GRYN	Native and Exotic Insects			(q7) Maybe lady bird beetles ephidrid flies and geothermal		(q11) depends on the species
Alpine plant community characteristics	GRTE	Alpine Meadow and Timberline Ecosystems		(q4) for mountain goats			
Fire and fuel loading	GRYN	Terrestrial Ecosystems				(q8) could be restricted to small areas	
Shrubland community composition and structure	GRYN	Montane Shrubland Ecosystems					(q12) could be combination of causes
Browse effects on riparian woody vegetation	GRYN	Riparian and Riverine Wetland Ecosystems					(q13) limited in extent

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Grassland annual net primary productivity	GRYN	Herbaceous Meadow and Grassland Ecosystems		(q3) However, there are models addressing certain stressors			(q13) selected park areas access to remote sensing
Grassland vegetation annual offtake	GRYN	Herbaceous Meadow and Grassland Ecosystems			(q6) but maybe in BICA	(q8) n/a - need to develop metric (q9) N/a (both scored no)	
Grassland nitrogen	GRYN	Herbaceous Meadow and Grassland Ecosystems		(q3) models in development, (q4) Need to consult N-expert	(q6) could be good mgmt tool.	(q9,10) N/A	
Bighorn basin plant community composition and exotic species	BICA	Terrestrial Ecosystems		(q5) beyond our expertise			
Lichen distribution, abundance and chemical composition	GRYN	Terrestrial Ecosystems		(q3) particularly in regard to growth and climate variables			(q13) yes in YELL, no in GRTE and BICA
Lodgepole pine plant community composition and exotic species	GRTE	Lodgepole Pine Forest Ecosystem		(q3) dependent upon resolution of data			(q13) for limited areas

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Lodgepole pine forest floor litter and coarse woody debris	GRTE	Lodgepole Pine Forest Ecosystem			(q7) indirect for YELL		
Landscape structure and heterogeneity	BICA	Terrestrial Ecosystems		(q3) This VS has high value, despite this issue			(q13) yes, but only for limited areas
Aboveground net primary productivity	GRYN	Terrestrial Ecosystems					(q12) this is ecosystem specific
Stand density of high-elevation live and dead whitebark pine trees	GRTE	Whitebark Pine Woodland and Forest Ecosystems					(q13) if low density stands, can use old photos
Mixed conifer plant community composition and exotic species	YELL	Mixed Conifer Forest Ecosystems					(q13) for limited areas
Mixed conifer snag density	GRTE	Mixed Conifer Forest Ecosystems					(q13) possibly some surveys

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Ponderosa pine plant community composition and exotic species	BICA	Ponderosa Pine Ecosystems					(q12) more useful for vegetation. responses than animal responses
Aspen community composition and structure	GRTE	Aspen Forest Ecosystems		(q5) variable often high			
Aspen stand extent and distribution in landscape	GRTE	Aspen Forest Ecosystems					(q13) Based upon estimates
Shrubland nitrogen	GRYN	Montane Shrubland Ecosystems		(q3) models in development	(q6) could be good management tool (q7) need to contact N-expert		
Shrubland exotic species	GRYN	Montane Shrubland Ecosystems					(q11) cannot be causal in interpretation (12) specific to different species (13) mostly anecdotal.

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Selected sensitive bird species abundance, distribution and productivity	GRYN	Birds		(q3)unknown cause of trumpeter decline (q5) Harlequins: yes, swan? Loons? Occupancy (PAO) is less variable, so yes			current, ongoing debate
Song bird population abundance and distribution	GRYN	Birds	(Q1) Many species which effect many levels of food web (q2) migratory, many habitats	(q3) relative to abiotic factors (q4) e.g.. DDT. (q5) perhaps use a PAO methodology, but not from a territorial male perspective	(q6) neotropical migrants (q7) e.g.. Cavity nesters in burns, people get exited about bird watching	(q8) point sampling methods are relatively straightforward (q9) point counts non-invasive (q10) requires use of highly trained personnel	(q11) esp. because of migration & wintering sites (q13) much historic data, but in different formats. Monitoring must be correlated with other methods
Colony nesting bird population abundance, distribution, vital rates and productivity	GRYN	Birds		(q3)"reasons for declines are uncertain" (q5) site occupancy is not variable, but abundance is more so.	(q7) colony nesting birds specifically noted in state of park reports	(q8) easy (q10) low-training	(q11) seeq 3 above. (q12) see q3 above. (q13) good historic data
Raptor population abundance, distribution and productivity	GRYN	Birds		(q5) using to site fidelity			

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Large carnivore population abundance and distribution	GRYN	Mammals	(q1) food web = top predators	(q4) food switching, functional response		(q8) very expensive due to life history. (q10) not easy, collaring animals is labor intensive	(q13) good for grizzlies. Short term for wolves. Questionable for mountain lions
Ungulate population abundance, distribution and productivity	GRYN	Mammals		(q4) long-lived so low sensitivity. (q5) high variability			(q11) don't know enough about compensatory mechanisms in the absence of hunting
Bat occurrence, distribution and abundance	GRYN	Mammals	(q2) trophic factors. Dispersed forager, roosts, foraging areas, and commuting zones	(q3,4) known responses but qable statistical power.	(q6) never mentioned, often conflicting with park maintenance issues. (q7) cave use, building and historic sites, mine use, forest roost structures.	(q8) abundance of non-colony roosters potentially labor-intensive	(q11) In many cases, yes (especially for roosts.) However, population fluctuations may require additional research to determine causation. (q13) Inventory is currently occurring, but virtually no older data.

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Native species richness	GRYN	Terrestrial Vertebrates		(q4) does not provide early warning. (Q5) The SNR increases with the proportion of rare animals in the richness calculation. This rank assumes focus on the species with high to moderate detectibility	(q6) maintenance of diversity at national level is a goal of NPS. (q7) Management action very difficult to tie to a list of species, as opposed to particular species.	(q8) see note at bottom of page	(q13) Inventories are currently being done to establish baselines.
Invasive vertebrate species richness and distribution	GRYN	Terrestrial Vertebrates	(q1) Key taxa: bullfrogs, raccoons, English sparrows, starlings, pigeons, turkeys, pheasants, mute swans, feral cats. Species displacement, disease.	(q4) early warning of change. (q5) without 'natural' in wording of q. Its presence or absence, not abundance			(q11) It is an anthropogenic impact. (q13) Historic (or prehistoric) baseline is zero-they were not here before.

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Vertebrate diseases	GRYN	Terrestrial Vertebrates		(q3) much current research to uncover causes of spread			(q11) Anthropogenic causes can interact with diseases, making wildlife more susceptible. (q13) Many diseases are recently discovered or recently prevalent. With molecular techniques the history of diseases can often be traced back in time.

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Beaver presence and population estimates	GRYN	Mammals		(q3) Known response to predators and habitat structure.(q4) Responsive to multi-scale phenomena (floods, fire, drought, stressors, geomorphology). Sensitive at local scales, but anticipatory at larger scales.		(q8) East to identify and measure.	(q13) Beaver flights have been conducted for years in YNP. Some survey data for GRTE.
Reptile occurrence	BICA	Terrestrial Vertebrates	(q1) Function: Trophic relationships. (q3) Links to various spatial scales are more tenuous than other groups (e.g.. Amphibians.)	(q3,4) Relative to other groups. (q5) PAO doesn't work well with reptiles		(q8) drift fences /funnel traps labor intensive. (q9)) drift fences /funnel traps are invasive but feasible in BICA.	(q11) insufficient baseline data. (q12) relative to amphibians

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Amphibian occurrence	GRYN	Terrestrial Vertebrates	(q1) Predator and prey in aquatic systems . Nutrient transport. Larvae are important herbivores. Function: connected food web. (q2) contingent of noted change in description- ('scales' changed to 'levels' 'and spatial and temporal scale' added at end	(q3) Sometimes, depending on a stressor. Usually predictable although power is qable. Using PAO methods may be statistically feasible. (q4) Amphibians are sensitive relative to other vital signs. (q5) Low variability if PAO is used as metric.	(q6) Direct impacts on: road construction, fish stocking, water management, water diversion, fuels reduction and prescribed burns. Mgmt. goals, GRPA, Business plan: People understand, Applications, Resource is cared about.	(q9,10) Contingent upon using PAO to monitor.	(q11) Yes, given that we have baseline data. (q12) There is documented use of amphibians to identify contaminants, water issues, fish stocking, etc. (q13) Extensive monitoring via PAO has been done for 3 yrs. Other survey data collected for 20-30 yrs
Rodents and insectivores (<250g) population, abundance and distribution	GRYN	Mammals	(q1) Key taxa; Red-backed voles, Microtus spp.. Pocket gophers. Key reasons: prey base, burrows for amphibians.		(q3,4,5) high variability		(q13) except BICA
Rodents and Lagomorphs (>250g) population, abundance and distribution	GRYN	Mammals	(q1) prey base	(q3) responsive to some major stressors that restructure systems. (q4,5) high variability			(q11) see response above. (q13) variable by park unit. Selected data, but not across the board.

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Meso-carnivore population abundance and distribution	GRYN	Mammals	(q1) many populations are remnant or restricted. (e.g.. Fisher, lynx) . Wolverine tied to ungulates, marten to old forest, lynx to hares, others qable.		(q6) e.g.. Lynx, wolverine	(q10) Low abundance hard to detect, difficult to prove breeding, abundance hard to show	q11) poor knowledge on linkages. (q13) species and park specific
Pattern of non-park land-use changes	GRYN	Terrestrial Vertebrates		(q3) Stressors may be socio-economic trends and land-use change is the response.			
Major ion chemistry	GRYN	Lakes and Reservoirs	(q1)-includes alkalinity (q1)-especially in areas subject to atmospheric deposition and possible salinity changes	(q3)-acidification has highest sensitivity (q3)-may be 'no' for other uses	(q7)-assumes future management decisions as well as past	(q8)-assumes cost effective protocols; maintain this core set at sites-recommend	(q11)-for individual ions 'yes'; others 'no' (q13)-may be available on a case-by-case basis
E. coli	GRYN	Lakes and Reservoirs			(q6)-this is mainly an issue for BICA		(q11)-'no' unless typing methods are employed (q13)-GRTE has a recent baseline

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Metals	GRYN	Lakes and Reservoirs	(q2)-it may be more valuable to monitor biota (for bioaccumulation) in addition to monitoring water or sediment	(q3)-behavior of species is often coupled to episodic events (q5)-but YELL provides an extremely high level of spatial variability		(q8)-there may be exceptions, Hg is an example	(q13)-data are limited in some geographic areas
Zooplankton community structure	GRYN	Lakes and Reservoirs					(q12)-but could be useful for major (catastrophic) change
Core parameters	GRYN	Rivers and Streams	(q1)-not as important as major ion chemistry; 'yes' in some cases (q2)-unless under the context of a specific q, such as lake thermal structure	(q3)-'yes' in extreme situations			
Periphyton community structure, chlorophyll a	GRYN	Rivers and Streams	(q1)-linkage may not be as strong as that demonstrated in lakes	(q5)-further research needed in the area 'community structure and nutrient concentration relationships'		(q8)-however the identification costs for algae may be high	(q11)-unless there is a major change

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Continuous water temperature	GRYN	Lakes and Reservoirs					(q11)-depends on the magnitude of the change
Watershed budgets	GRYN	Watersheds	(q1)-integrates among ecosystems and among other ecological indicators (q2)-provides a foundation to integrate other measurements			(q8)-but many of these data are collected as part of other indicators; may be cheap	(q11)-but over decadal time scales

APPENDIX I-RANKED LIST OF CANDIDATE VITAL SIGNS BY RESOURCE AREA

**Please note: an overall ranked list of candidate vital signs is available upon request.

	Attribute	Secondary Resource	Score	GRTE	YELL	BICA
Air Quality						
	Atmospheric deposition of nitrogen, sulfur and all major anions and cations		1.00	X	X	X
	Atmospheric deposition and response in sensitive headwater catchments		1.00	X	X	
	Change in visibility deciviews		1.00	X	X	X
	Deposition and accumulation of mercury in biota		0.57	X	X	X
	Over-snow vehicles emissions and effects		0.40	X	X	
Aquatic Communities						
	Native and exotic community structure, composition, stability	Aquatic Species at risk	1.00	X	X	X
	Native fish genetic integrity	Aquatic Species at risk	1.00	X	X	
	Fish pathogens and disease	Aquatic Pathogens/disease	0.77	X	X	X
Aquatic Habitats						
	Stream reach geomorphology	Rivers and Streams	0.78	X	X	X
Climate						
	Basic climatological measurements	Climate, Biotic and Abiotic	1.00	X	X	X
	Date of "spring green-up"	Climate, Biotic and Abiotic	1.00	X	X	X
	Date of ice on/off on major lakes	Climate, Biotic and Abiotic	1.00	X	X	X
	Snow cover	Climate, Biotic and Abiotic	1.00	X	X	X
	Stream gauging	Climate, Biotic and Abiotic	1.00	X	X	X
	Glaciers retreat or increase	Climate, Biotic and Abiotic	0.80	X	X	
	Soil climate	Climate, Biotic and Abiotic	0.75	X	X	X
	Extreme Climatological Events	Climate, Biotic and Abiotic	0.53	X	X	X
Geology and Geothermal						
	Chloride flux in thermal features	Geothermal Processes	1.00		X	
	Geothermal water chemistry	Geothermal Processes	0.95	X	X	
	Heat flow	Geothermal Processes	0.95	X	X	
	Stream sediment transport	Geomorphic Processes	0.95	X	X	X
	Earthquake activity	Geologic Processes	0.87	X	X	X
	Emission rates of CO2, H2S, SO2, volatile Hg, and He to the atmosphere over Yellowstone NP	Geothermal Processes	0.87		X	

	Attribute	Secondary Resource	Score	GRTE	YELL	BICA
	Stream channel change	Geomorphic Processes	0.87	X		
	Landslide and debris flows	Geomorphic Processes	0.87		X	
	Landslide and debris flows	Geomorphic Processes	0.82	X		X
	Level and temperature of groundwater associated with thermal features	Geothermal Processes	0.82		X	
	Soil moisture/temperature/structure	Soils	0.82	X	X	
	Plant community composition and exotic species	Geothermal Ecosystem	0.78	X	X	
	Geothermal feature abundance & distribution	Geothermal Processes	0.73	X	X	
	Geothermal microbial diversity	Geothermal Microbiology	0.73	X		
	Geyser eruption volume and rate	Geothermal Processes	0.72		X	
	Stream channel change	Geomorphic Processes	0.67		X	X
	Soil chemistry	Soils	0.61	X	X	X
	Geothermal water flow rate	Geothermal Processes	0.51		X	
	Soil structure and stability	Soils	0.47	X	X	X
Human Activities						
	Landscape and habitat fragmentation	Surrounding Environments	1.00	X	X	X
	Park infrastructure	Park Visitation	0.83	X	X	X
	Levels of backcountry day use	Park Visitation	0.75	X	X	
	Levels of backcountry overnight use	Park Visitation	0.75	X	X	
	Resource consumptive use and hydrologic modification	Park Visitation	0.57	X	X	X
	Visitor use levels	Park Visitation	0.52	X	X	X
	Resource violations	Park Visitation	0.45	X	X	X
Invertebrates - Terrestrial and Aquatic						
	Forest/grassland/shrubland defoliators and consumers	Native and Exotic Insects	0.77	X	X	X
	Exotic insects	Native and Exotic Insects	0.70	X	X	X
	Native insect biodiversity and distribution	Native and Exotic Insects	0.56	X	X	X
	Selected insect species of concern	Native and Exotic Insects	0.42	X	X	X
Terrestrial Vegetation						
	Grassland vegetation community composition and structure	Herbaceous Meadow and Grassland Ecosystems	1.00	X	X	X
	Alpine plant community characteristics	Alpine Meadow and Timberline Ecosystems	0.95	X	X	
	Lichen distribution, abundance and chemical composition	Terrestrial Ecosystems	0.95	X	X	X

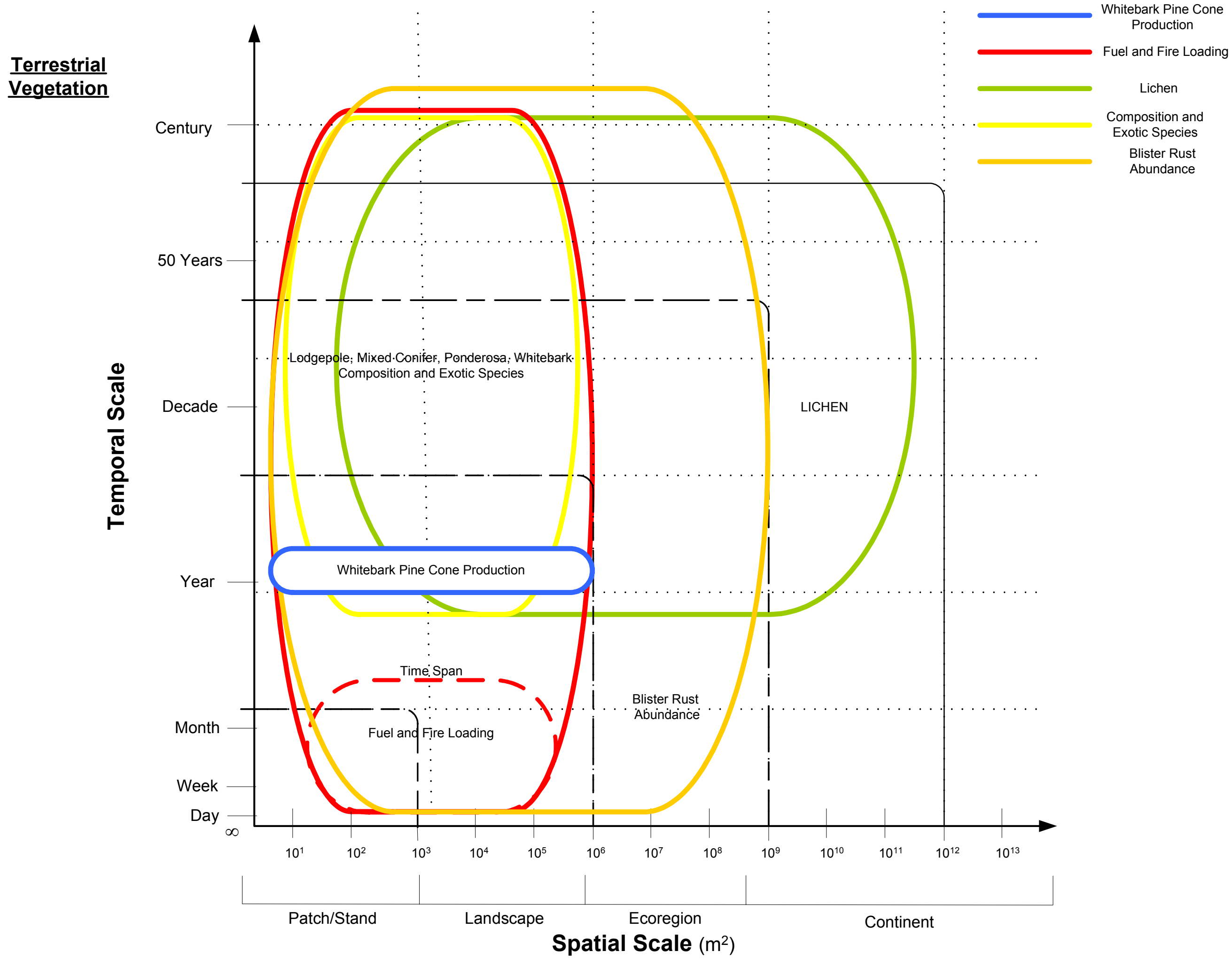
	Attribute	Secondary Resource	Score	GRTE	YELL	BICA
	Shrubland community composition and structure	Montane Shrubland Ecosystems	0.95	X	X	X
	Aspen community composition and structure	Aspen Forest Ecosystems	0.92	X	X	
	Browse effects on riparian woody vegetation	Riparian and Riverine Wetland Ecosystems	0.92	X	X	X
	Fire and fuel loading	Terrestrial Ecosystems	0.92	X	X	X
	Plant community composition and exotic species	Whitebark Pine Woodland and Forest Ecosystems	0.92		X	
	Plant community composition and exotic species	Mixed Conifer Forest Ecosystems	0.92		X	
	Plant community composition and exotic species	Lodgepole Pine Forest Ecosystem	0.92	X	X	
	Riparian vegetation community structure and composition	Riparian and Riverine Wetland Ecosystems	0.90	X	X	X
	Shrubland exotic species	Montane Shrubland Ecosystems	0.90	X	X	X
	Wetland extent	Wet Meadow, Spring, and Depressional Wetland Ecosystems	0.90	X	X	X
	Exotic plants in riparian zone	Riparian and Riverine Wetland Ecosystems	0.87	X	X	X
	Wetland plant cover and composition	Wet Meadow, Spring, and Depressional Wetland Ecosystems	0.85	X	X	X
	Blister Rust abundance and spread	Whitebark Pine Woodland and Forest Ecosystems	0.83	X	X	
	Browsing effects within aspen stands	Aspen Forest Ecosystems	0.83	X	X	
	Plant community composition and exotic species	Terrestrial Ecosystems	0.83			X
	Plant community composition and exotic species	Ponderosa Pine Ecosystems	0.83			X
	Timberline forest density and health	Alpine Meadow and Timberline Ecosystems	0.82	X	X	
	Whitebark pine cone production	Whitebark Pine Woodland and Forest Ecosystems	0.78	X	X	
	Landscape structure and heterogeneity	Terrestrial Ecosystems	0.75	X		
	Dry woodland community structure and composition	Dry Woodland Ecosystems	0.70			X
	Extent and distribution of woodlands	Dry Woodland Ecosystems	0.70			X
	Snag density	Whitebark Pine Woodland and Forest Ecosystems	0.68	X	X	
	Snag density	Mixed Conifer Forest Ecosystems	0.68	X	X	

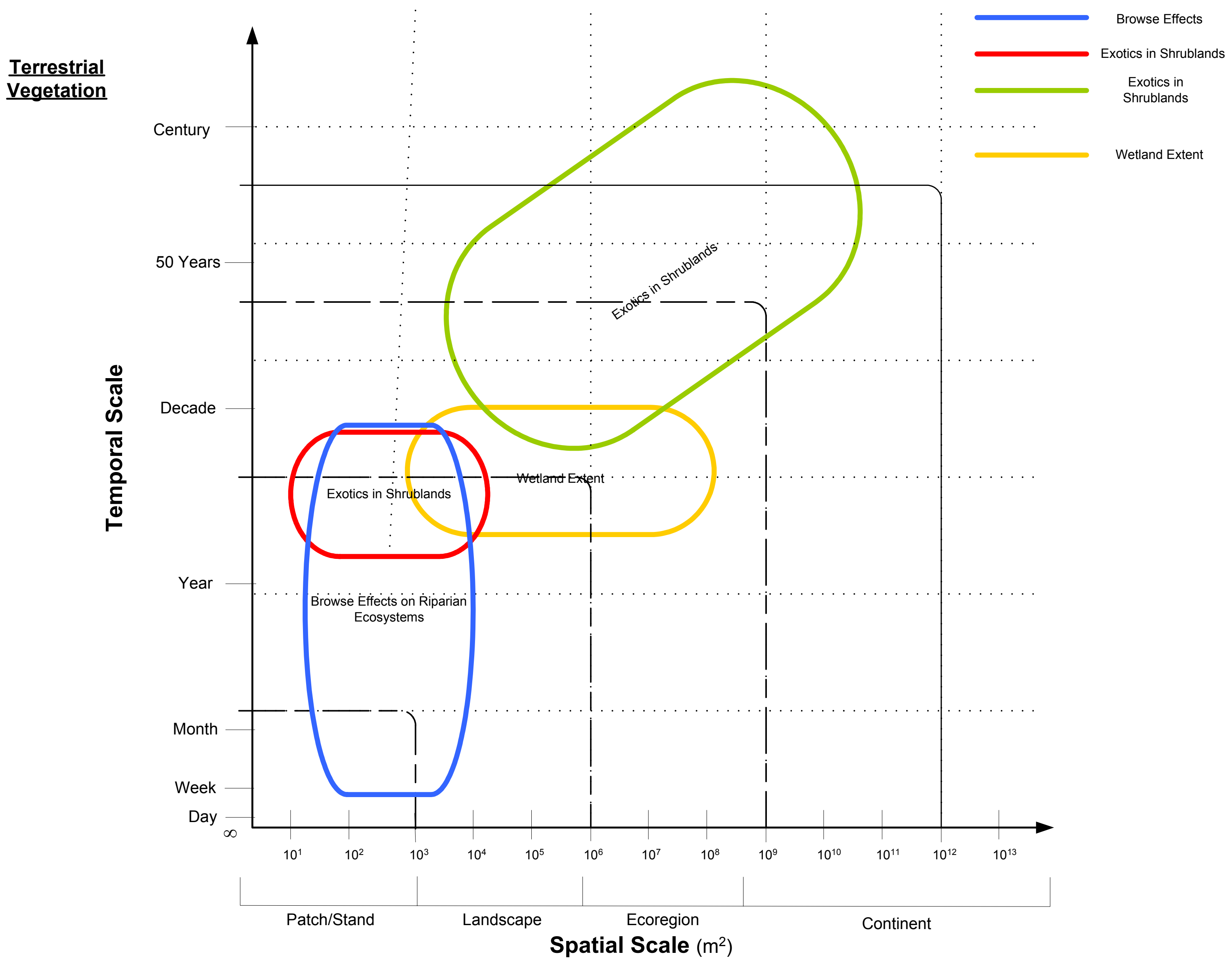
	Attribute	Secondary Resource	Score	GRTE	YELL	BICA
	Snag density	Lodgepole Pine Forest Ecosystem	0.68	X	X	
	Timberline elevation boundaries	Alpine Meadow and Timberline Ecosystems	0.67	X	X	
	Landscape structure and heterogeneity	Terrestrial Ecosystems	0.65		X	
	Stand density of high-elevation live and dead whitebark pine trees	Whitebark Pine Woodland and Forest Ecosystems	0.63	X	X	
	Aspen stand extent and distribution in landscape	Aspen Forest Ecosystems	0.60	X	X	
	Forest floor litter and coarse woody debris	Mixed Conifer Forest Ecosystems	0.60	X	X	
	Forest floor litter and coarse woody debris	Lodgepole Pine Forest Ecosystem	0.55	X	X	
	Landscape structure and heterogeneity	Terrestrial Ecosystems	0.55			X
	Stand density of live and dead trees	Ponderosa Pine Ecosystems	0.53			X
	Aboveground net primary productivity	Terrestrial Ecosystems	0.50	X	X	X
	Grassland annual net primary productivity	Herbaceous Meadow and Grassland Ecosystems	0.45	X	X	X
	Grassland nitrogen	Herbaceous Meadow and Grassland Ecosystems	0.38	X	X	X
	Shrubland nitrogen	Montane Shrubland Ecosystems	0.38	X	X	X
	Grassland vegetation annual offtake	Herbaceous Meadow and Grassland Ecosystems	0.13	X	X	X
Terrestrial Vertebrates						
	Amphibian occurrence	Terrestrial Vertebrates	1.00	X	X	X
	Beaver presence and population estimates	Mammals	1.00	X	X	X
	Pattern of non-park land-use changes	Terrestrial Vertebrates	1.00	X	X	X
	Invasive vertebrate species richness and distribution	Terrestrial Vertebrates	0.92	X	X	X
	Vertebrate diseases	Terrestrial Vertebrates	0.92	X	X	X
	Raptor population abundance, distribution and productivity	Birds	0.87	X	X	X
	Selected sensitive bird species abundance, distribution and productivity	Birds	0.87	X	X	X
	Colony nesting bird population abundance, distribution, vital rates and productivity	Birds	0.82	X	X	X
	Ungulate population abundance, distribution and productivity	Mammals	0.78	X	X	X
	Song bird population abundance and distribution	Birds	0.73	X	X	X
	Bat occurrence, distribution and abundance	Mammals	0.72	X	X	X

	Attribute	Secondary Resource	Score	GRTE	YELL	BICA
	Large carnivore population abundance and distribution	Mammals	0.60	X	X	X
	Meso-carnivore population abundance and distribution	Mammals	0.60	X	X	X
	Rodents and Lagomorphs (>250g) population, abundance and distribution	Mammals	0.58	X	X	X
	Native species richness	Terrestrial Vertebrates	0.53	X	X	X
	Rodents and insectivores (<250g) population, abundance and distribution	Mammals	0.50	X	X	X
	Reptile occurrence	Terrestrial Vertebrates	0.22			X
Water Quality						
	Ground water hydrology	Ground Water	1.00	X	X	X
	Reservoir elevation	Lakes and Reservoirs	1.00	X		X
	Streamflow	Rivers and Streams	1.00	X	X	X
	Algal species composition and biomass	Lakes and Reservoirs	0.95	X	X	X
	Continuous water temperature	Lakes and Reservoirs	0.95	X	X	X
	Continuous water temperature	Rivers and Streams	0.95	X	X	X
	Ground water chemistry	Ground Water	0.95	X	X	X
	Major ion chemistry	Rivers and Streams	0.95	X	X	X
	Major ion chemistry	Lakes and Reservoirs	0.95	X	X	X
	River invertebrate assemblages	Rivers and Streams	0.95	X	X	X
	Bed sediment chemistry (adsorbed)	Rivers and Streams	0.82	X	X	X
	Bed sediment shemistry (adsorbed)	Lakes and Reservoirs	0.82	X	X	X
	Metals	Rivers and Streams	0.69	X	X	X
	Metals	Lakes and Reservoirs	0.69	X	X	X
	Periphyton community structure, chlorophyll a	Rivers and Streams	0.58	X	X	X
	Zooplankton community structure	Lakes and Reservoirs	0.48	X	X	X
	E. coli	Rivers and Streams	0.38	X	X	X
	E. coli	Lakes and Reservoirs	0.38	X	X	X
	Field parameters	Rivers and Streams	0.38	X	X	X
Watershed						
	Watershed budgets	Watersheds	0.90	X	X	X

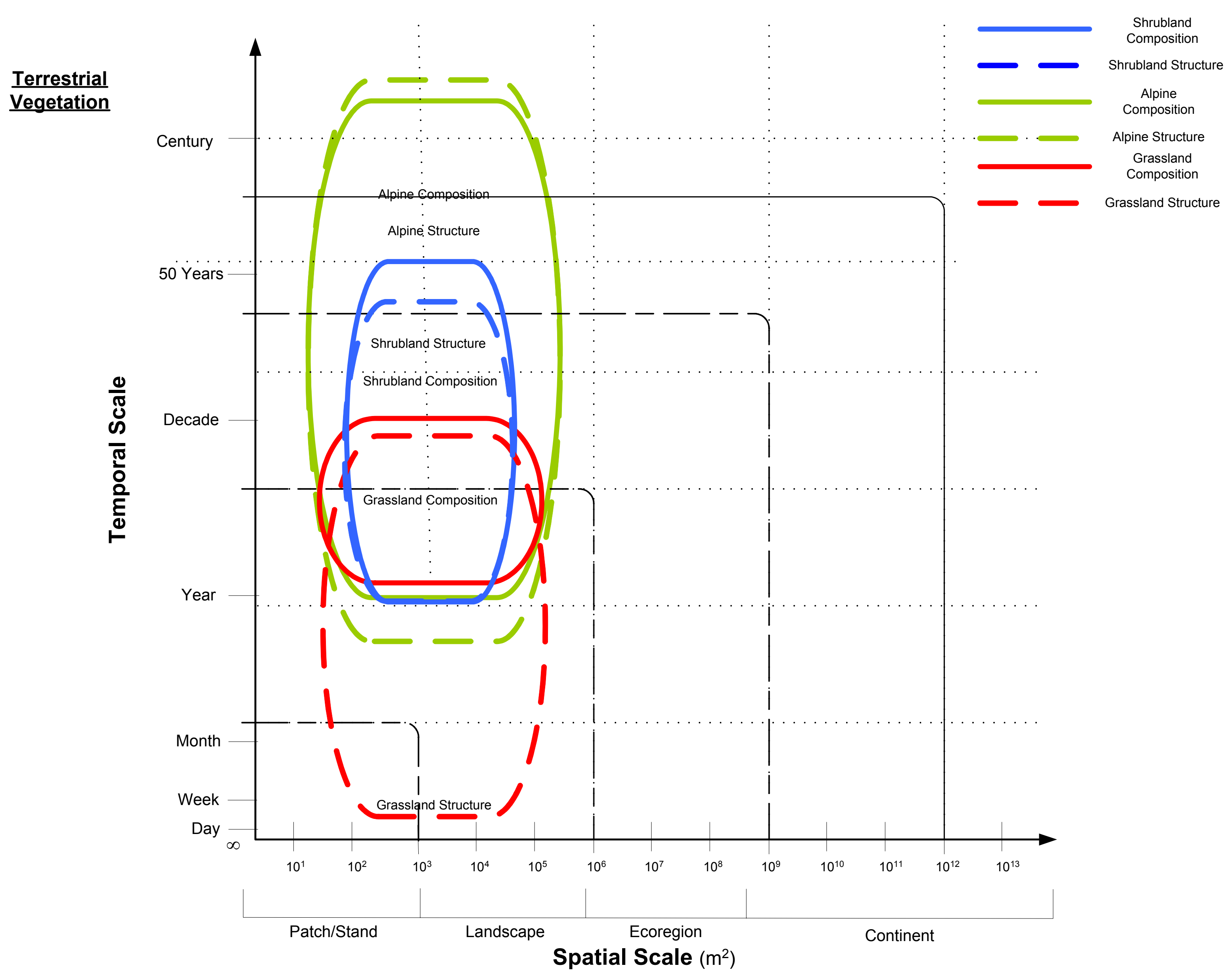
Appendix J-Spatio-temporal Models

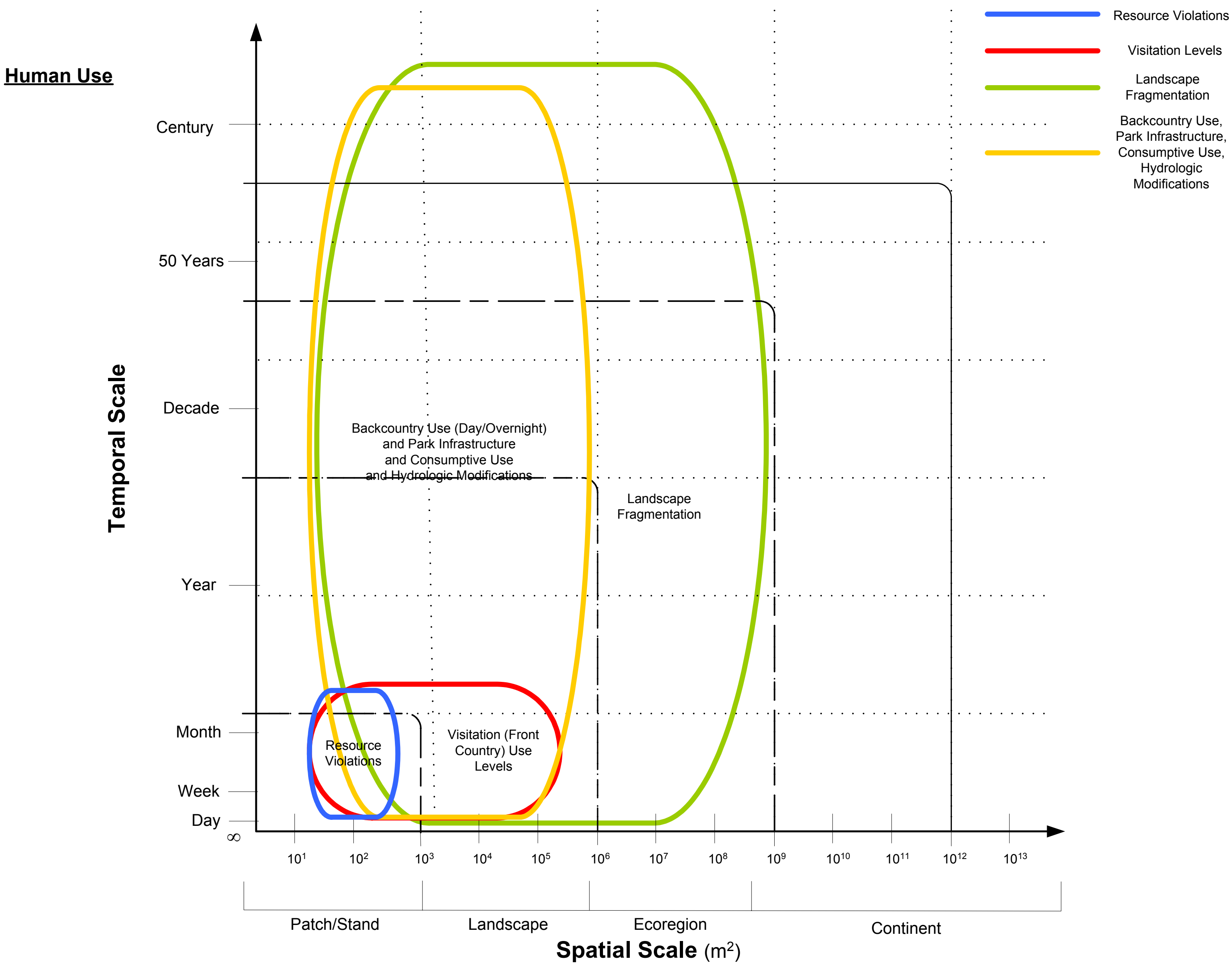
**Please note: these models are reproduction of those made by the breakout groups on day three of the workshop.

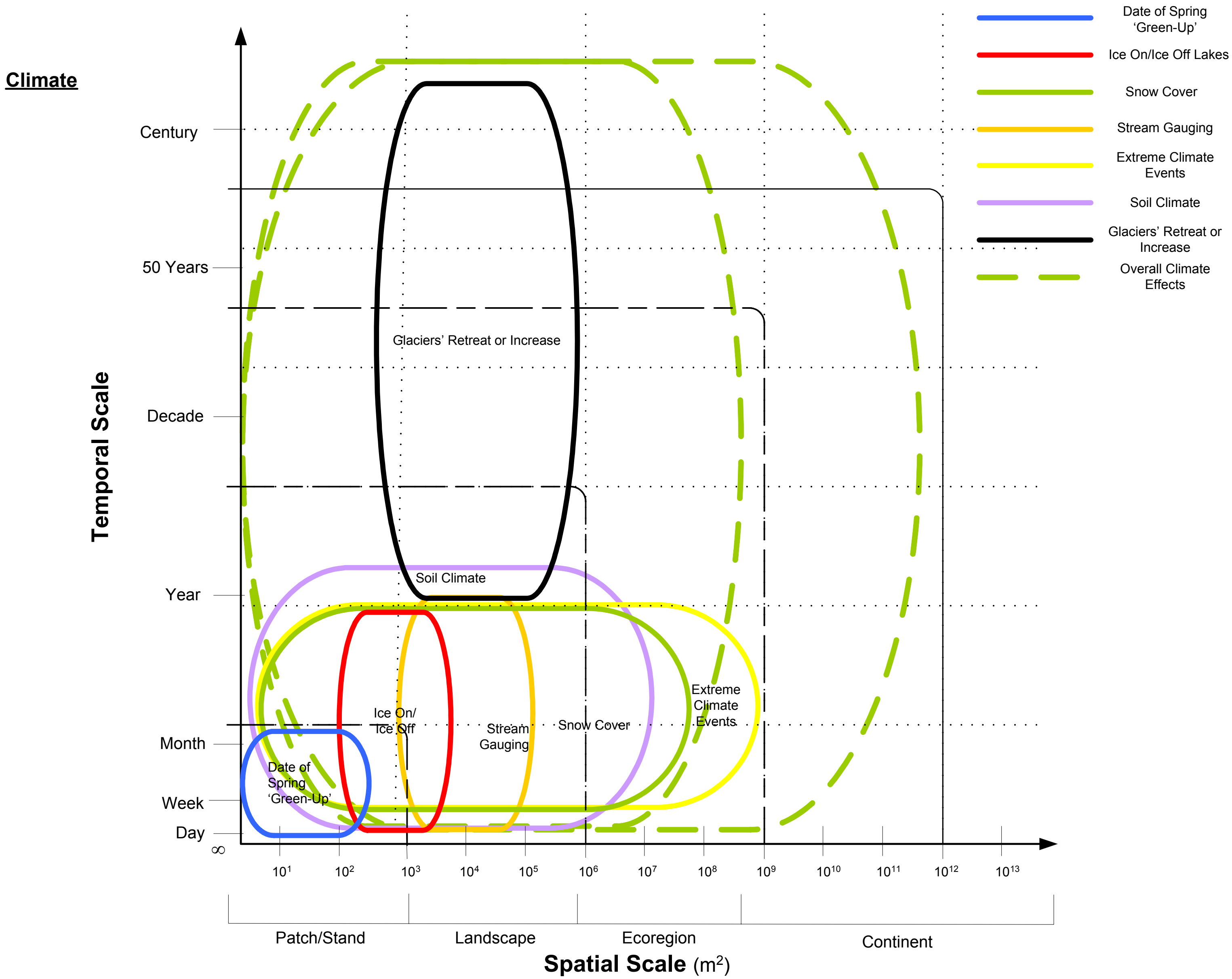




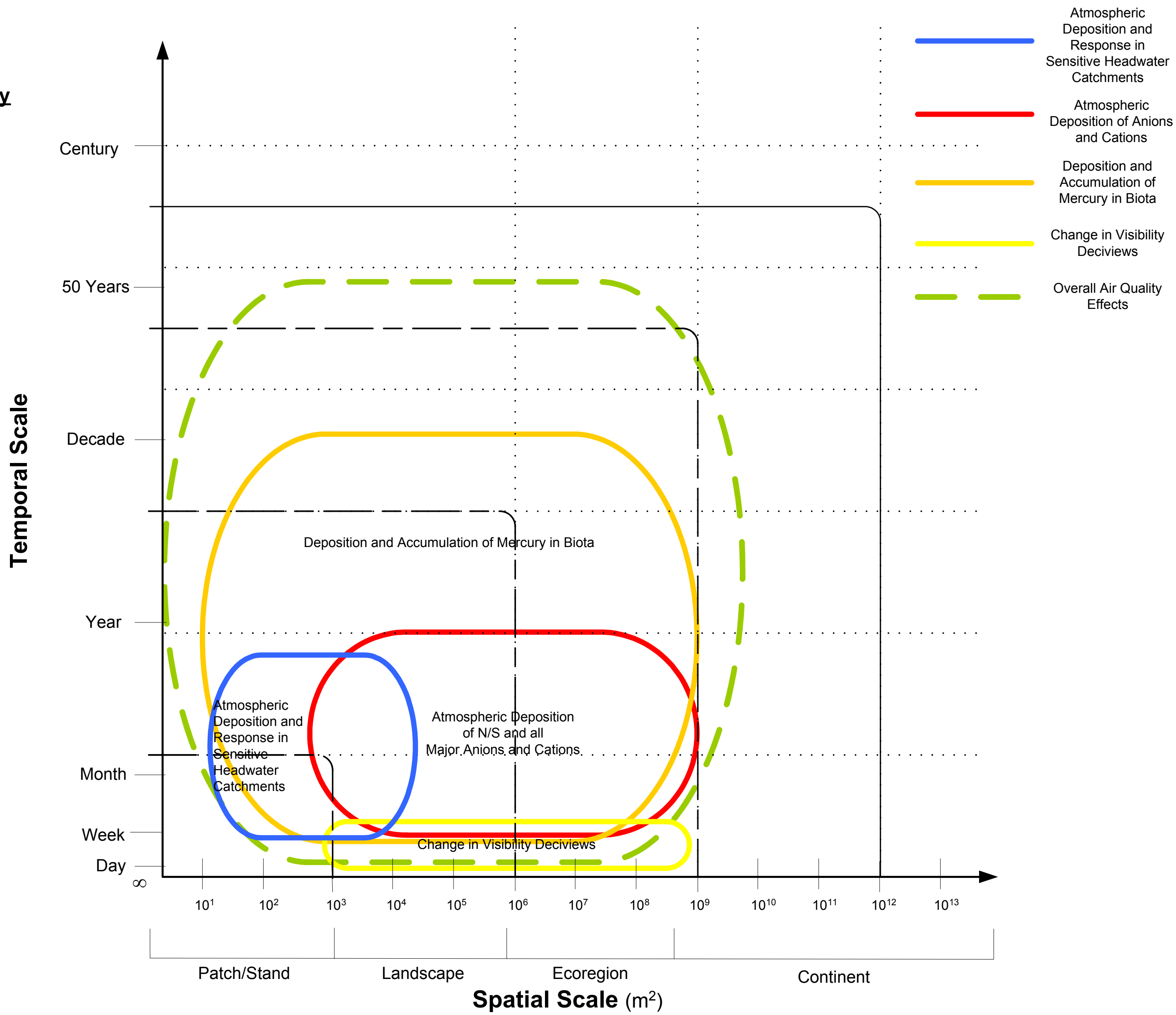
Terrestrial Vegetation
Browse Effects
Exotics in Shrublands
Exotics in Shrublands
Wetland Extent
Century
50 Years
Decade
Year
Month
Week
Day
∞
Temporal Scale
Exotics in Shrublands
Wetland Extent
Exotics in Shrublands
Browse Effects on Riparian Ecosystems
10^1
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
Patch/Stand
Landscape
Ecoregion
Continent
Spatial Scale (m^2)

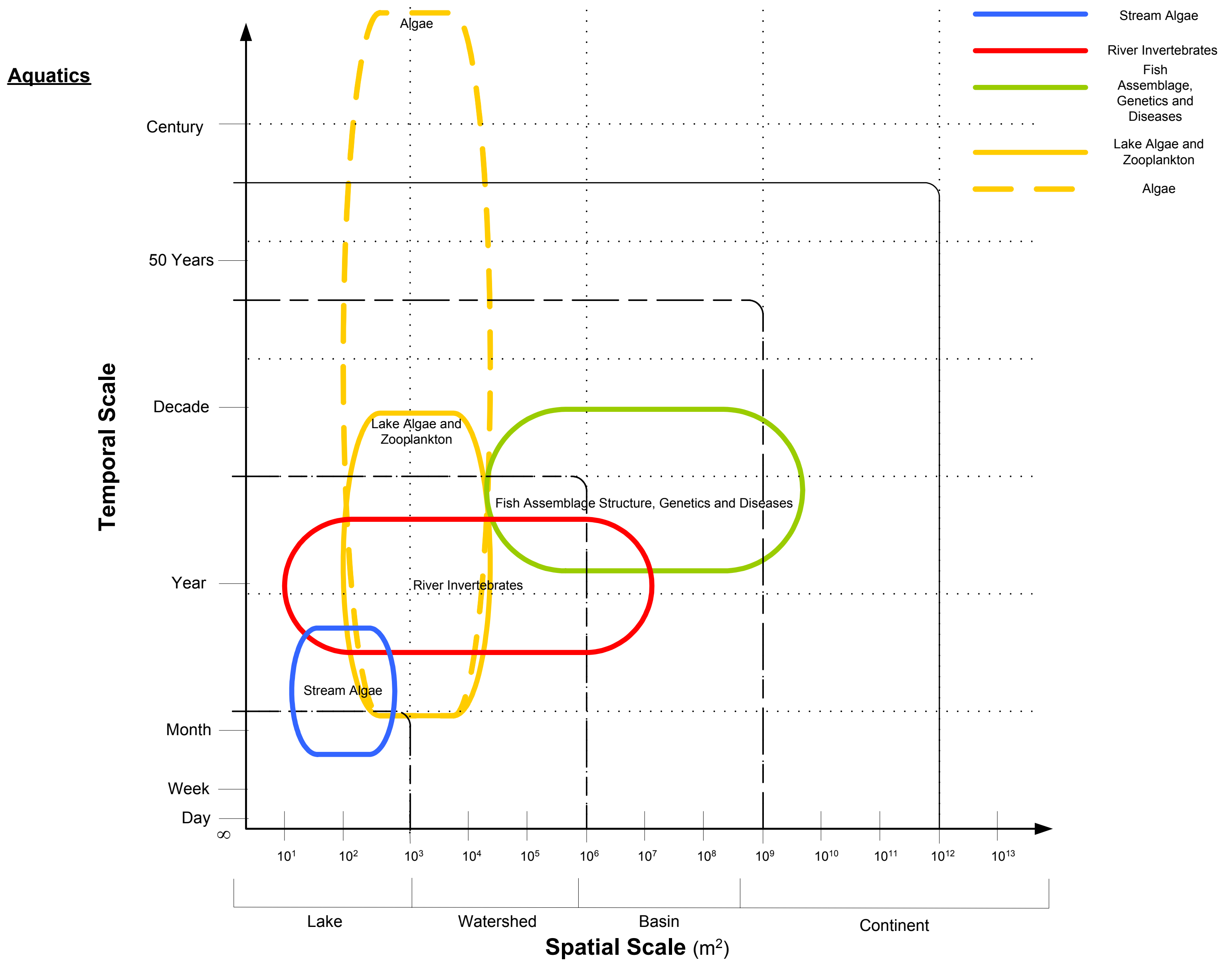

Terrestrial Vegetation
Temporal Scale
Century
50 Years
Decade
Year
Month
Week
Day
∞
Alpine Composition
Alpine Structure
Shrubland Structure
Shrubland Composition
Grassland Composition
Grassland Structure
Shrubland Composition
Shrubland Structure
Alpine Composition
Alpine Structure
Grassland Composition
Grassland Structure
10^1
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
Patch/Stand
Landscape
Ecoregion
Continent
Spatial Scale (m^2)

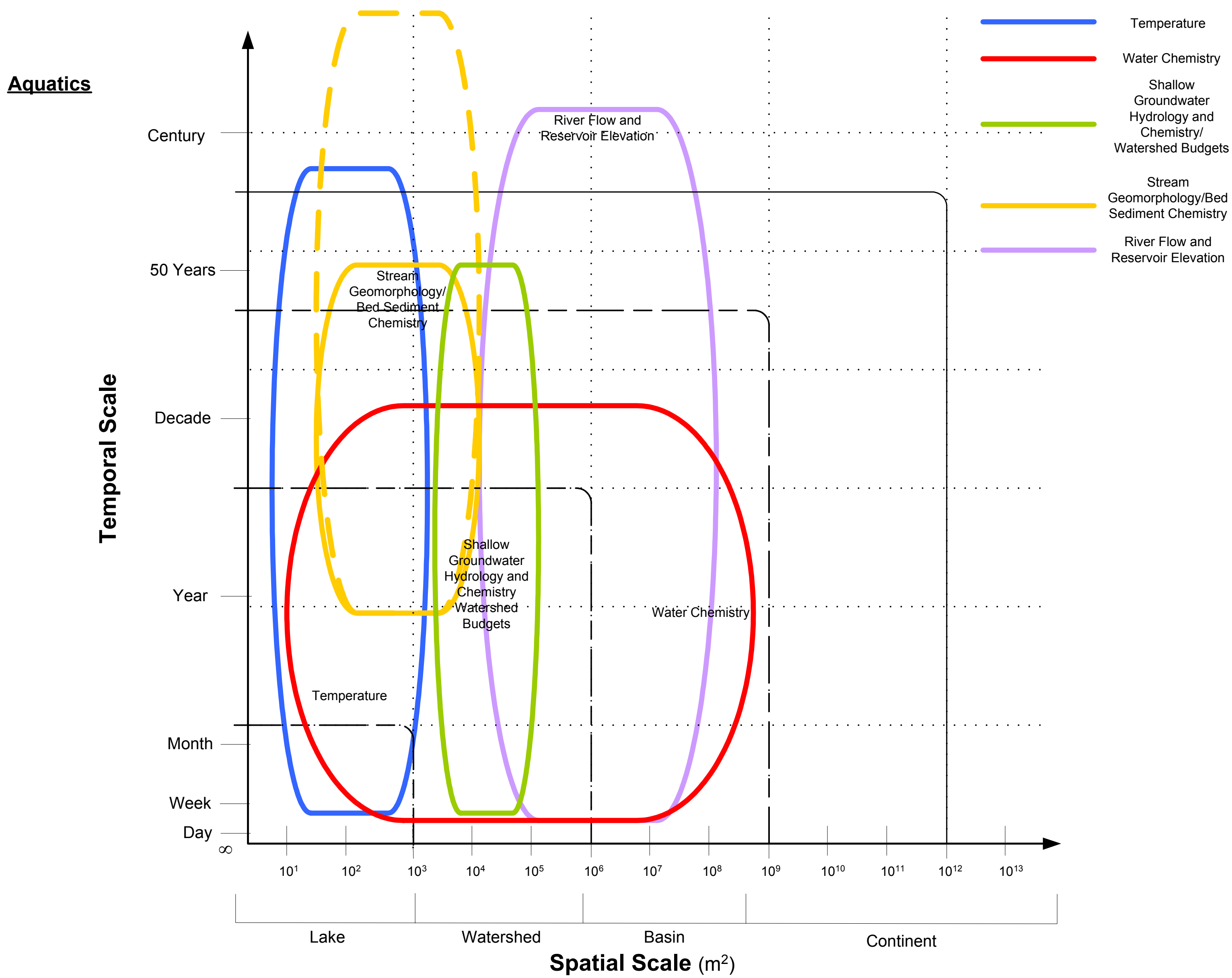

Human Use
Resource Violations
Visitation Levels
Landscape Fragmentation
Backcountry Use, Park Infrastructure, Consumptive Use, Hydrologic Modifications
Temporal Scale
Century
50 Years
Decade
Year
Month
Week
Day
∞
Backcountry Use (Day/Overnight) and Park Infrastructure and Consumptive Use and Hydrologic Modifications
Landscape Fragmentation
Resource Violations
Visitation (Front Country) Use Levels
10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13}
Patch/Stand
Landscape
Ecoregion
Continent
Spatial Scale (m^2)

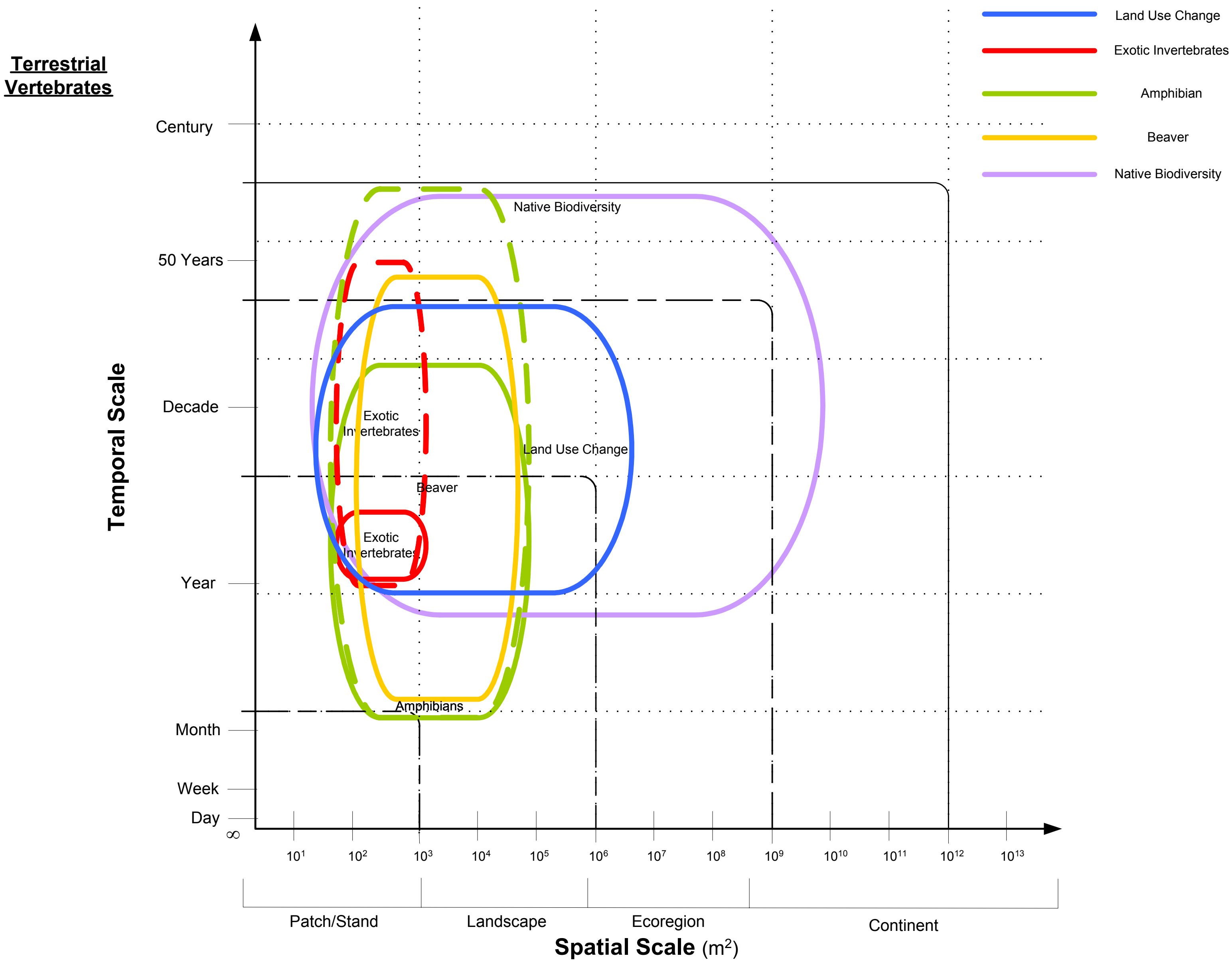

Climate
Date of Spring 'Green-Up'
Ice On/Ice Off Lakes
Snow Cover
Stream Gauging
Extreme Climate Events
Soil Climate
Glaciers' Retreat or Increase
Overall Climate Effects
Century
50 Years
Decade
Year
Month
Week
Day
∞
Temporal Scale
Glaciers' Retreat or Increase
Soil Climate
Ice On/ Ice Off
Stream Gauging
Snow Cover
Extreme Climate Events
Date of Spring 'Green-Up'
10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13}
Patch/Stand
Landscape
Ecoregion
Continent
Spatial Scale (m²)

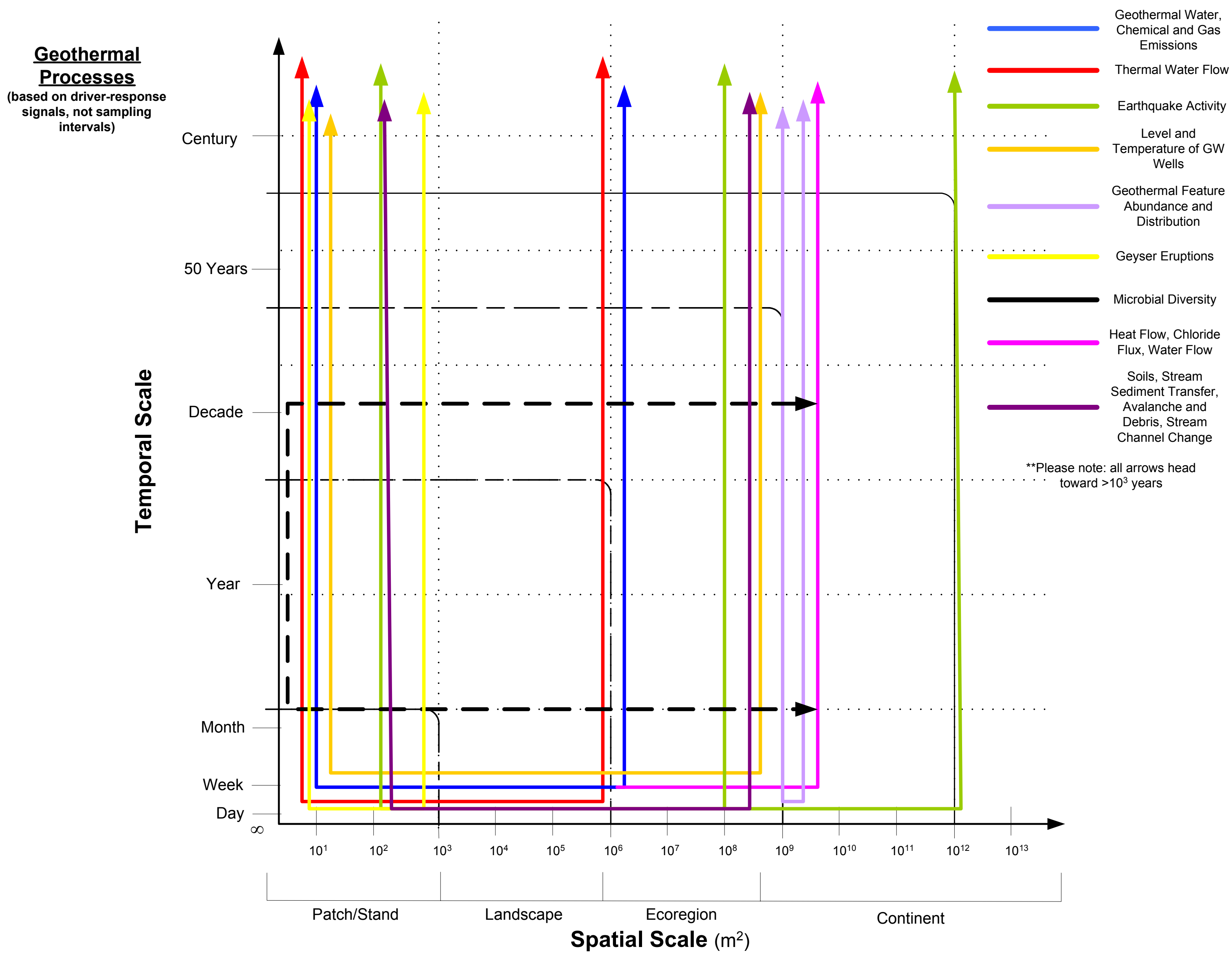
Air Quality


Century
50 Years
Decade
Year
Month
Week
Day
∞
Temporal Scale
Deposition and Accumulation of Mercury in Biota
Atmospheric Deposition and Response in Sensitive Headwater Catchments
Atmospheric Deposition of N/S and all Major Anions and Cations
Change in Visibility Deciviews
10¹ 10² 10³ 10⁴ 10⁵ 10⁶ 10⁷ 10⁸ 10⁹ 10¹⁰ 10¹¹ 10¹² 10¹³
Patch/Stand
Landscape
Ecoregion
Continent
Spatial Scale (m²)
Atmospheric Deposition and Response in Sensitive Headwater Catchments
Atmospheric Deposition of Anions and Cations
Deposition and Accumulation of Mercury in Biota
Change in Visibility Deciviews
Overall Air Quality Effects


Aquatics
Temporal Scale
Century
50 Years
Decade
Year
Month
Week
Day
∞
Algae
Lake Algae and Zooplankton
Fish Assemblage Structure, Genetics and Diseases
River Invertebrates
Stream Algae
10^1
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
Lake
Watershed
Basin
Continent
Spatial Scale (m^2)
Stream Algae
River Invertebrates
Fish Assemblage, Genetics and Diseases
Lake Algae and Zooplankton
Algae


Aquatics
Temporal Scale
Century
50 Years
Decade
Year
Month
Week
Day
∞
10^1
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
Lake
Watershed
Basin
Continent
Spatial Scale (m^2)
River Flow and Reservoir Elevation
Stream Geomorphology/ Bed Sediment Chemistry
Shallow Groundwater Hydrology and Chemistry Watershed Budgets
Water Chemistry
Temperature
Temperature
Water Chemistry
Shallow Groundwater Hydrology and Chemistry/ Watershed Budgets
Stream Geomorphology/Bed Sediment Chemistry
River Flow and Reservoir Elevation


Terrestrial Vertebrates
Land Use Change
Exotic Invertebrates
Amphibian
Beaver
Native Biodiversity
Century
50 Years
Decade
Year
Month
Week
Day
Temporal Scale
Native Biodiversity
Exotic Invertebrates
Land Use Change
Beaver
Exotic Invertebrates
Amphibians
10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13}
Patch/Stand
Landscape
Ecoregion
Continent
Spatial Scale (m^2)


Geothermal Processes
(based on driver-response signals, not sampling intervals)
Temporal Scale
Century
50 Years
Decade
Year
Month
Week
Day
∞
10^1
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^10
10^11
10^12
10^13
Patch/Stand
Landscape
Ecoregion
Continent
Spatial Scale (m^2)
Geothermal Water, Chemical and Gas Emissions
Thermal Water Flow
Earthquake Activity
Level and Temperature of GW Wells
Geothermal Feature Abundance and Distribution
Geyser Eruptions
Microbial Diversity
Heat Flow, Chloride Flux, Water Flow
Soils, Stream Sediment Transfer, Avalanche and Debris, Stream Channel Change
**Please note: all arrows head toward >10^3 years